The Far-Infrared Spectrum

Exploring a New Frontier in the
Remote Sensing of Earth's Climate

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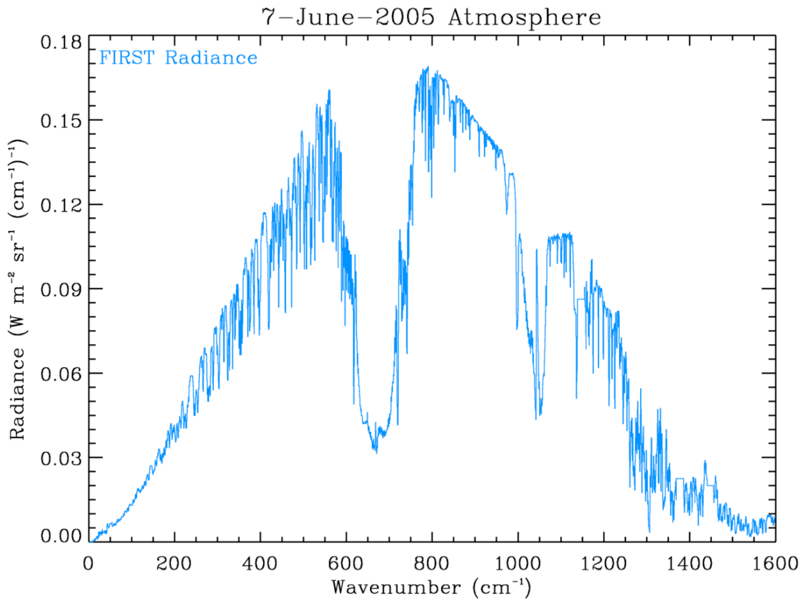
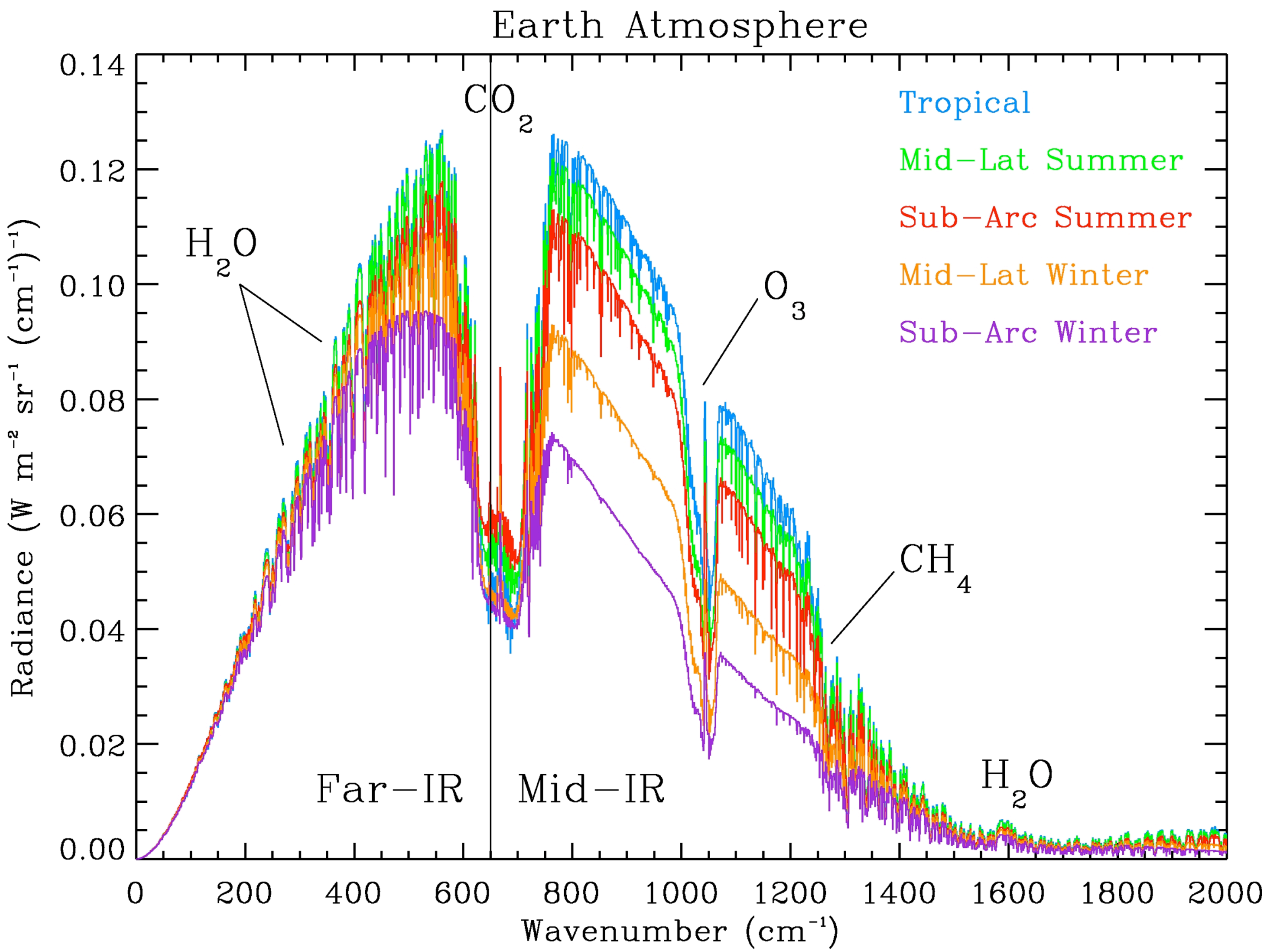


FIRST

Outline

- Science Motivation and Justification for Far-IR Measurement
- FIRST Project Description
    - Flight results 2005 and 2006
- The Greenhouse Effect at the Ends of the Earth
- On to Space
- Summary

Top-of-Atmosphere Spectral Infrared Radiance



FIRST

Compelling Science of the Far-Infrared

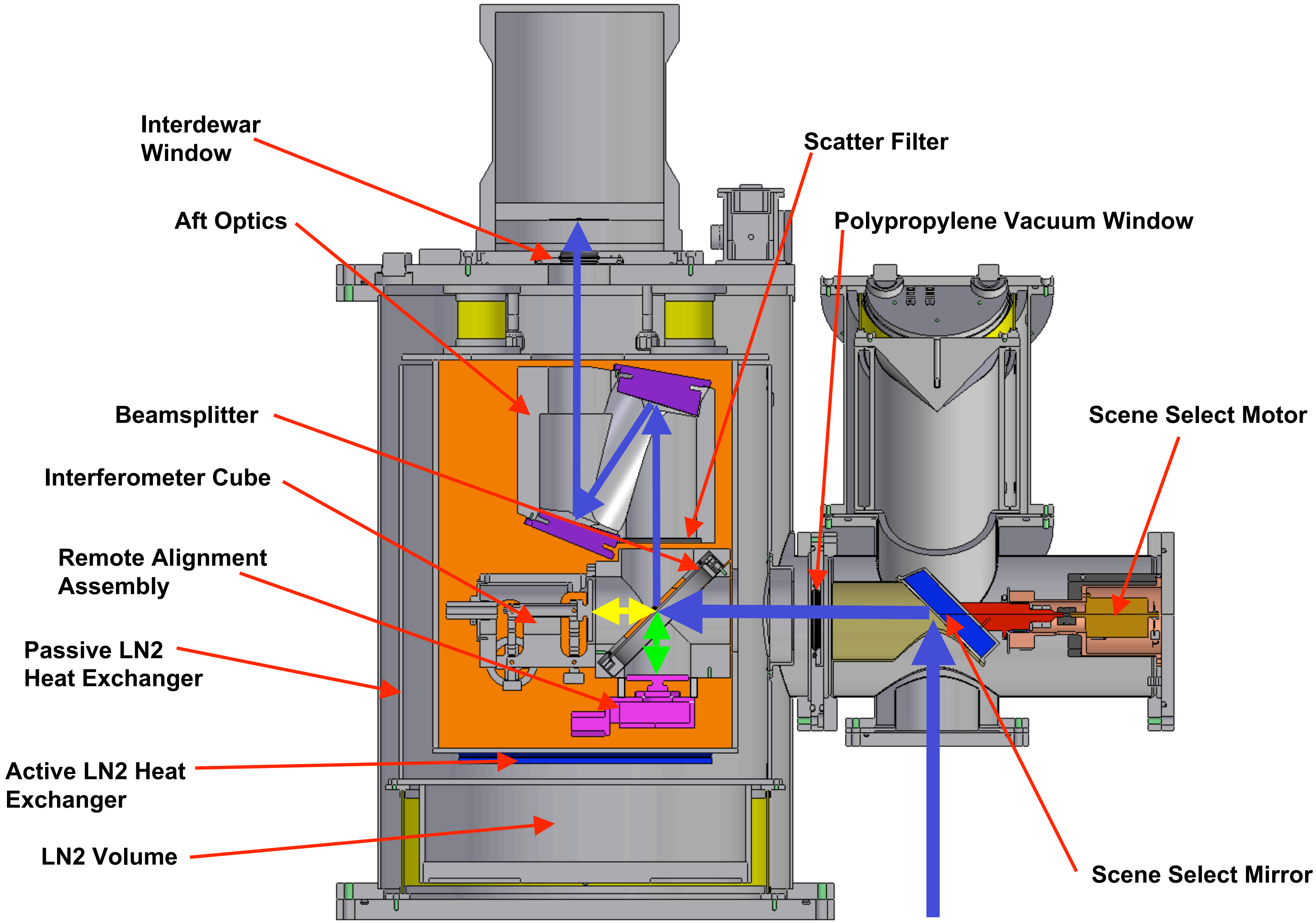
- Up to 50% of OLR (surface + atmosphere) is beyond 15.4 μm
- Between 50% and 75% of the atmosphere OLR is beyond 15.4 μm
- Basic greenhouse effect (~50%) occurs in the far-IR
- Clear sky cooling of the free troposphere occurs in the far-IR
  - Potential to derive atmospheric cooling rates directly from radiances
- Upper Tropospheric H_2O radiative feedbacks occur in far-IR
- Cirrus radiative forcing has a major component in the far-IR
- Longwave cloud forcing in tropical deep convection occurs in the far-IR
- Addresses remaining “dimension” – the spectral dimension – of ERB sampling

FIRST - Instrument Description

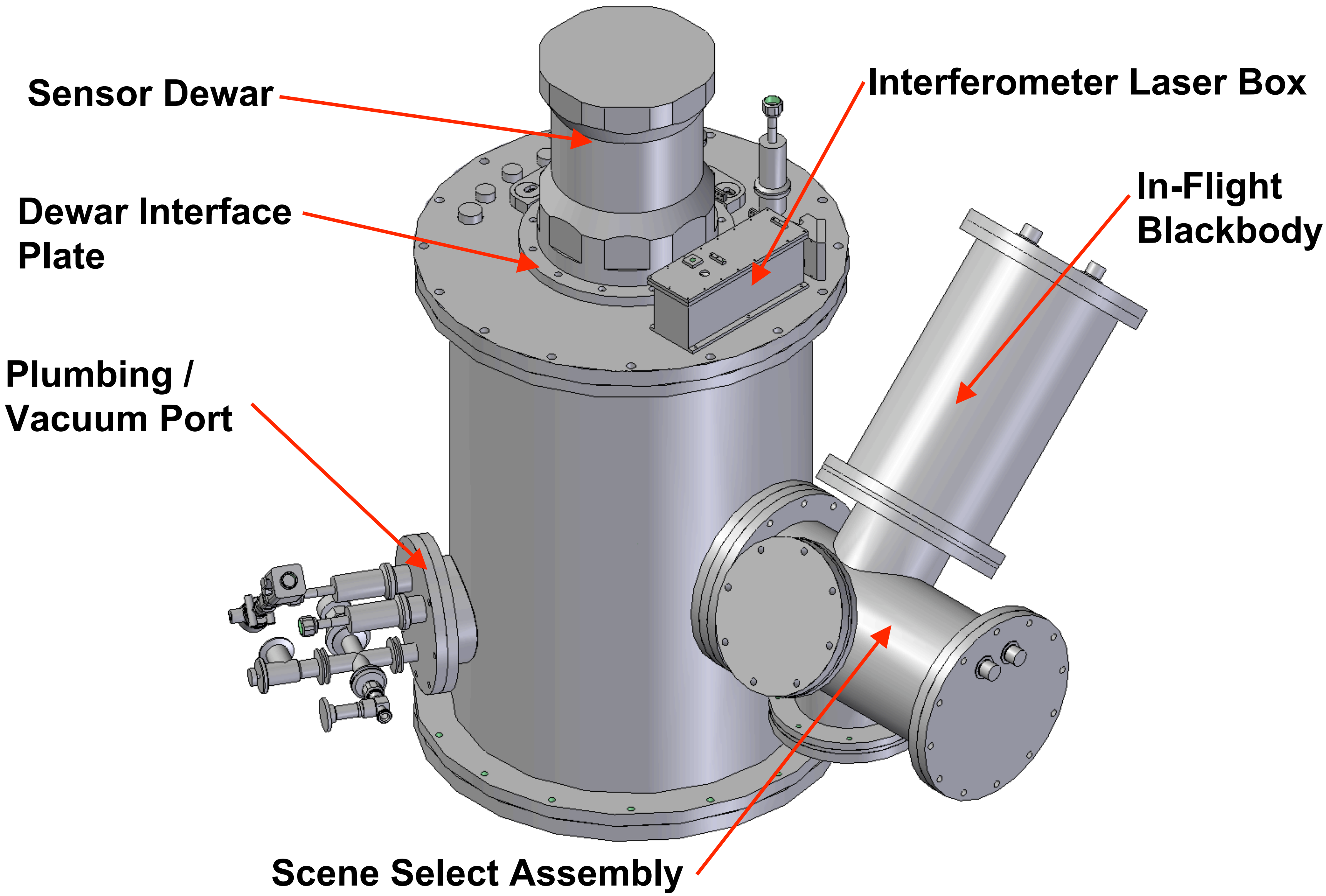
- Michelson Interferometer
- 6 to 100 μm on a single focal plane
- 0.625 cm^{-1} unapodized (0.8 cm OPD)
- 1.4 s scan time (nominal)
- 0.47 cm^2 sr optical throughput (realized)
- 10 discrete detector focal plane (sized for 100 @ 10 x 10)
- Germanium on polypropylene beamsplitter
- Bolometer (COTS) detectors @ 4 K
- NEΔT – Realized 0.2 K over most of wavelength range
- Demonstrated on a high-altitude balloon flight June 7 2005
- Second balloon flight September 18 2006

Designed to demonstrate technology to measure daily, the far-IR spectrum, globally, @ 10 km resolution

FIRST Balloon Payload System



FIRST Balloon Payload System



FIRST – Calibration

- FIRST designed with absolute calibration in mind, from the start
  - Instrument cooled to 180 K to simulate space environment and reduce instrument background
  - Full field external calibration sources
  - Multiple calibration sources (warm, cold) in laboratory
  - Multiple calibration sources in flight (warm, “space”)
- Spectral range designed to cover 10 – 15 μm (+ far-IR)
  - Allows verification against “standard” instruments, e.g, AIRS, AERI, in mid-IR

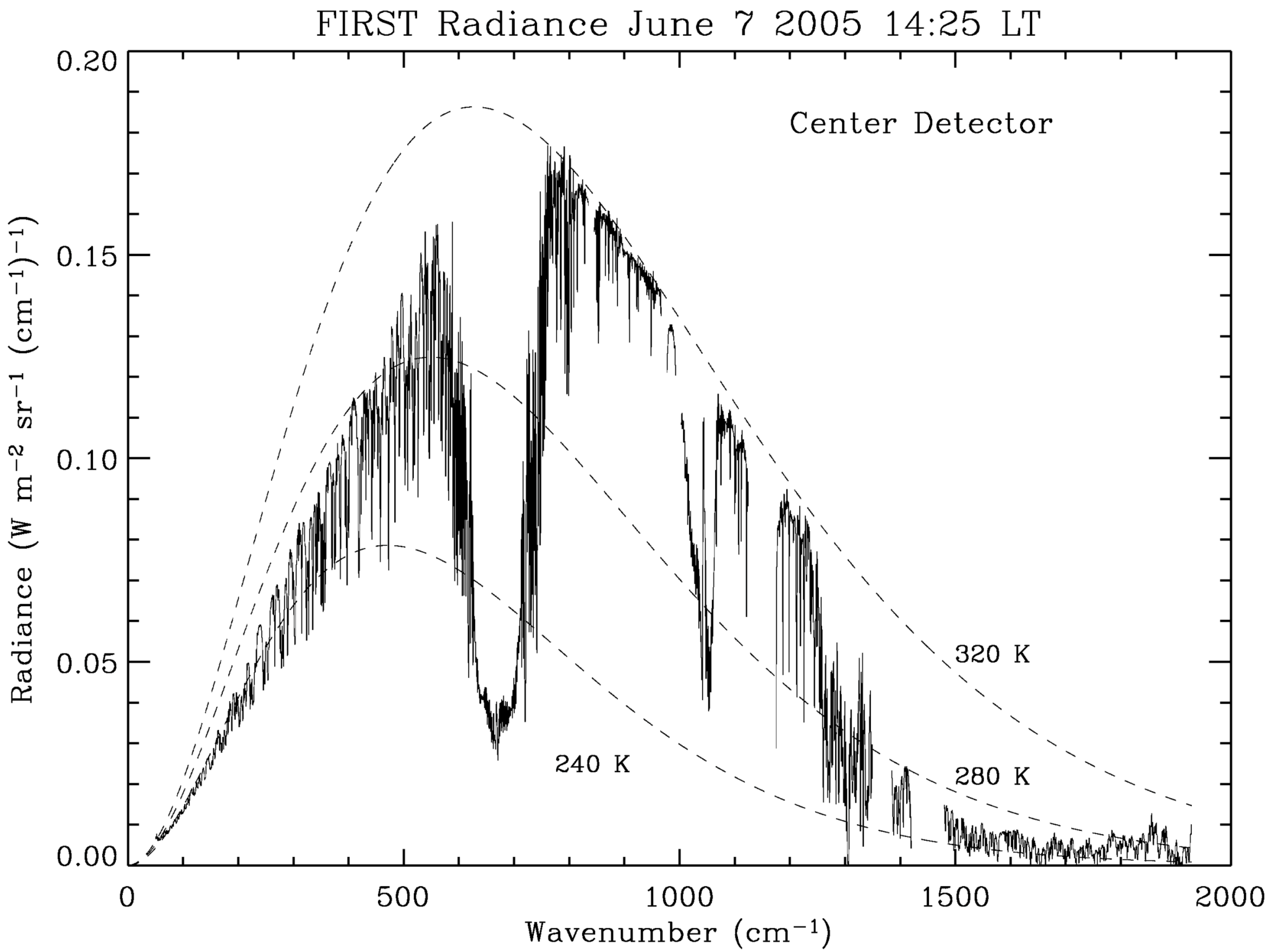
FIRST on the Flight Line June 7 2005

FIRST Flights

- Launched on 11 M cu ft balloon June 7 2005; September 18 2006
- Float altitude of 27 km, 33 km
- Recorded ~ 6 hours of data at float
- 1.2 km footprint of entire FPA; 0.2 km footprint per detector
- 15,000 interferograms (total) recorded on 10 detectors
- Overflight of AQUA at 2:25 pm local time – AIRS, CERES, MODIS
- Essentially coincident footprints FIRST, AQUA instruments
- FIRST met or exceeded technology development goals
- FIRST, AIRS, CERES comparisons in window imply excellent calibration (better than 1 K agreement in skin temperature)

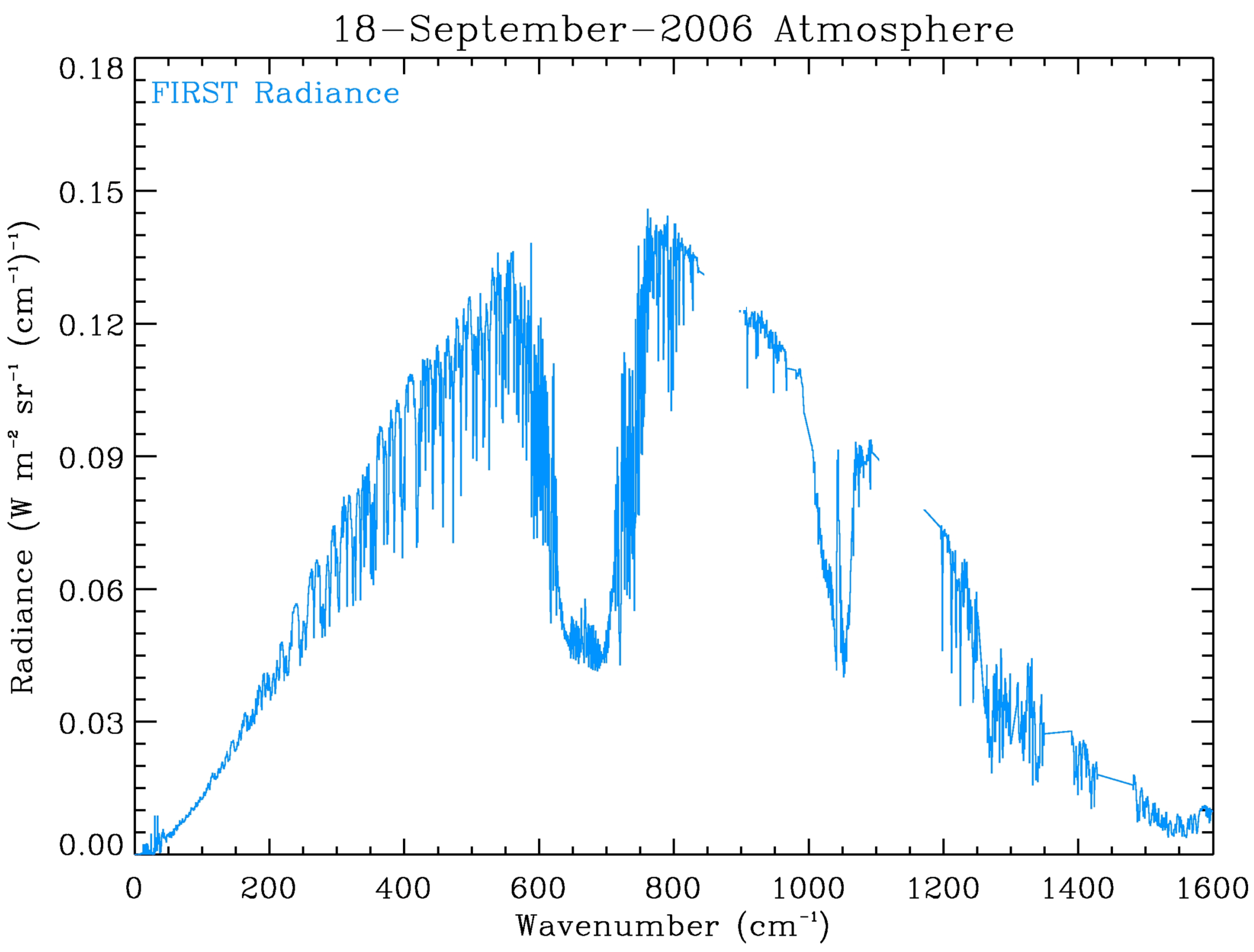
FIRST records complete thermal emission spectrum of the Earth at high spatial and spectral resolution

FIRST Spectrum, Center Detector

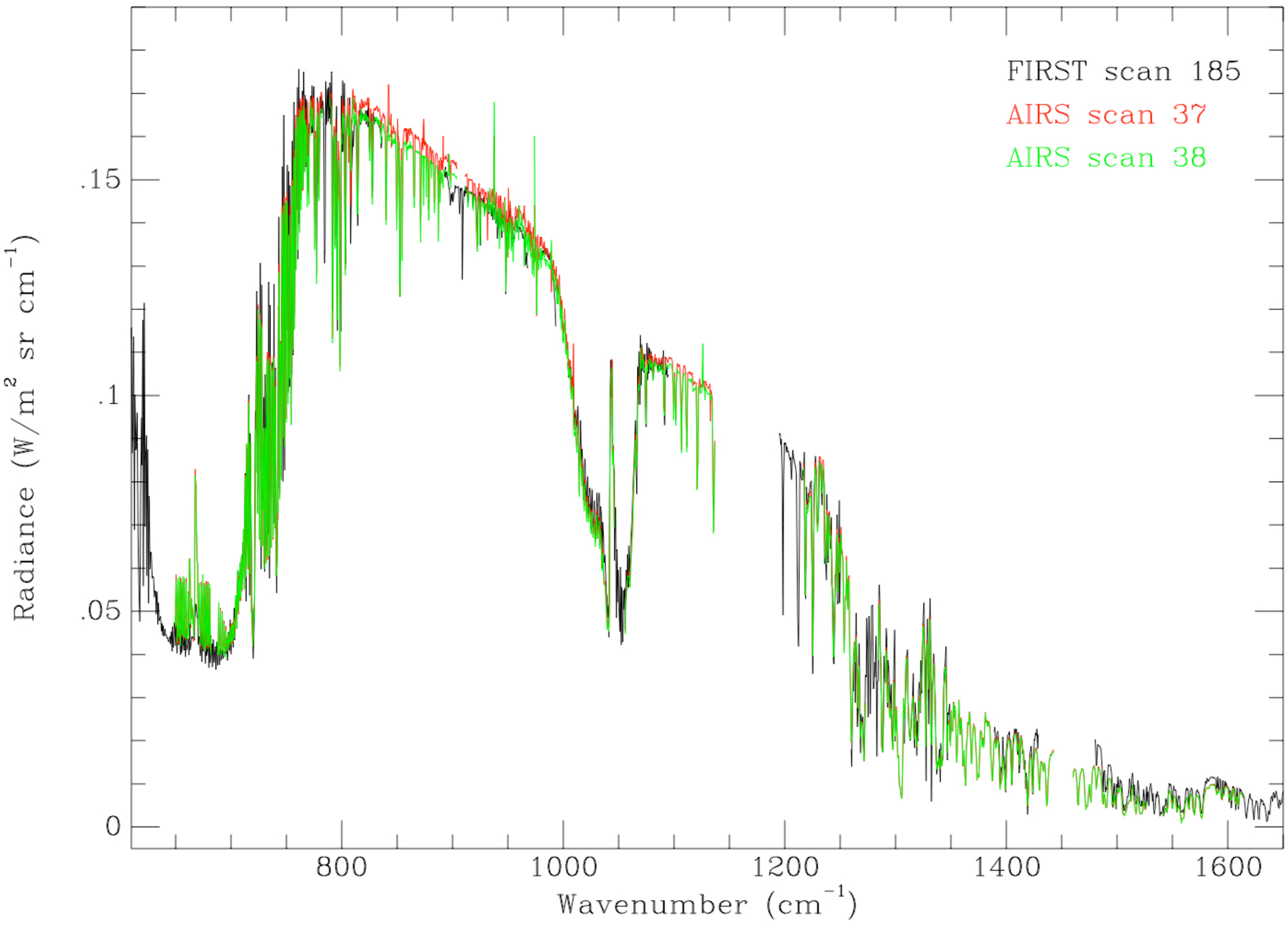


Mlynczak et al., GRL, 2006

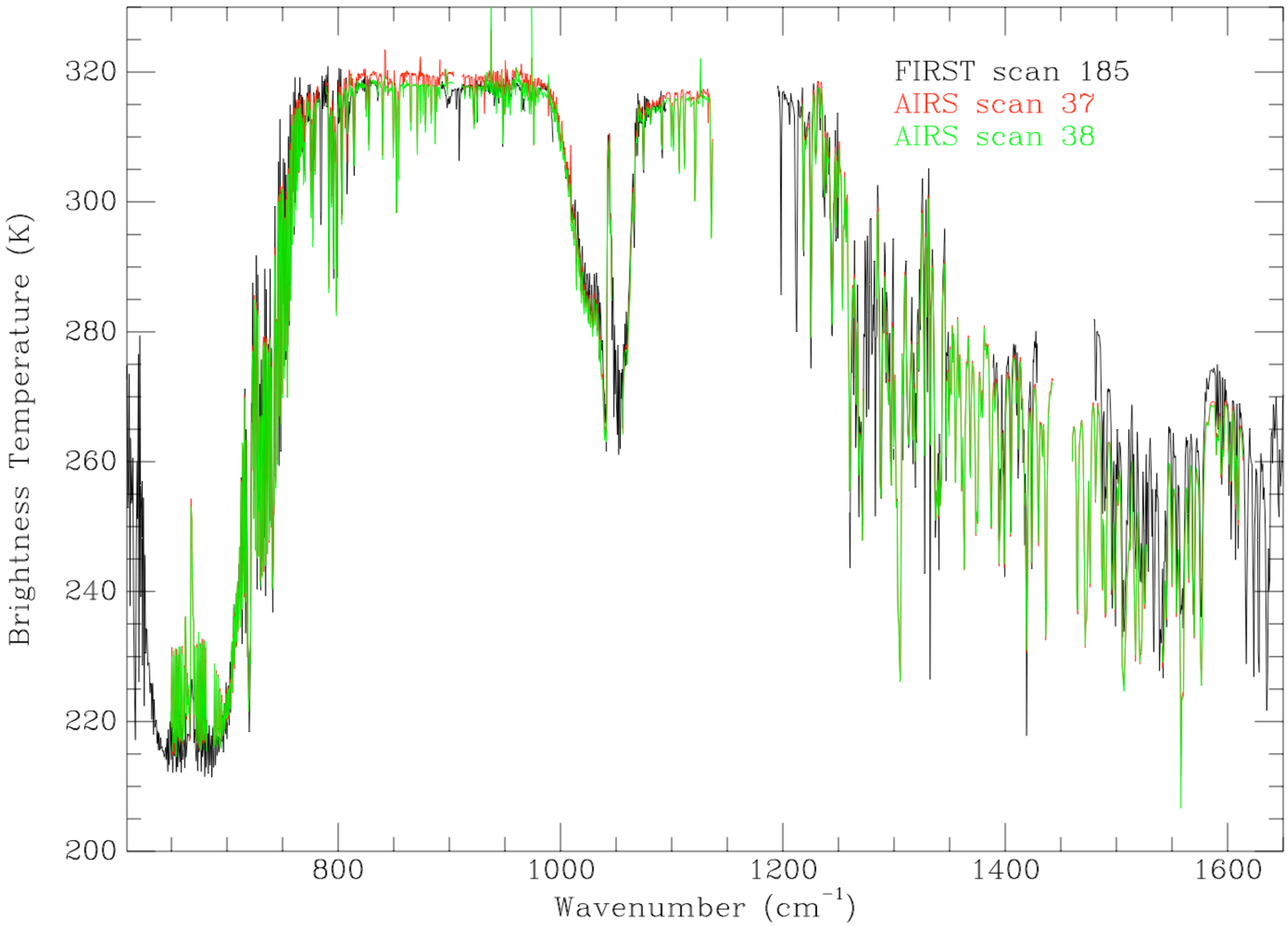
FIRST Spectrum September 2006



FIRST and AIRS Radiance Comparison June 2005



FIRST and AIRS T_B Comparison June 2005



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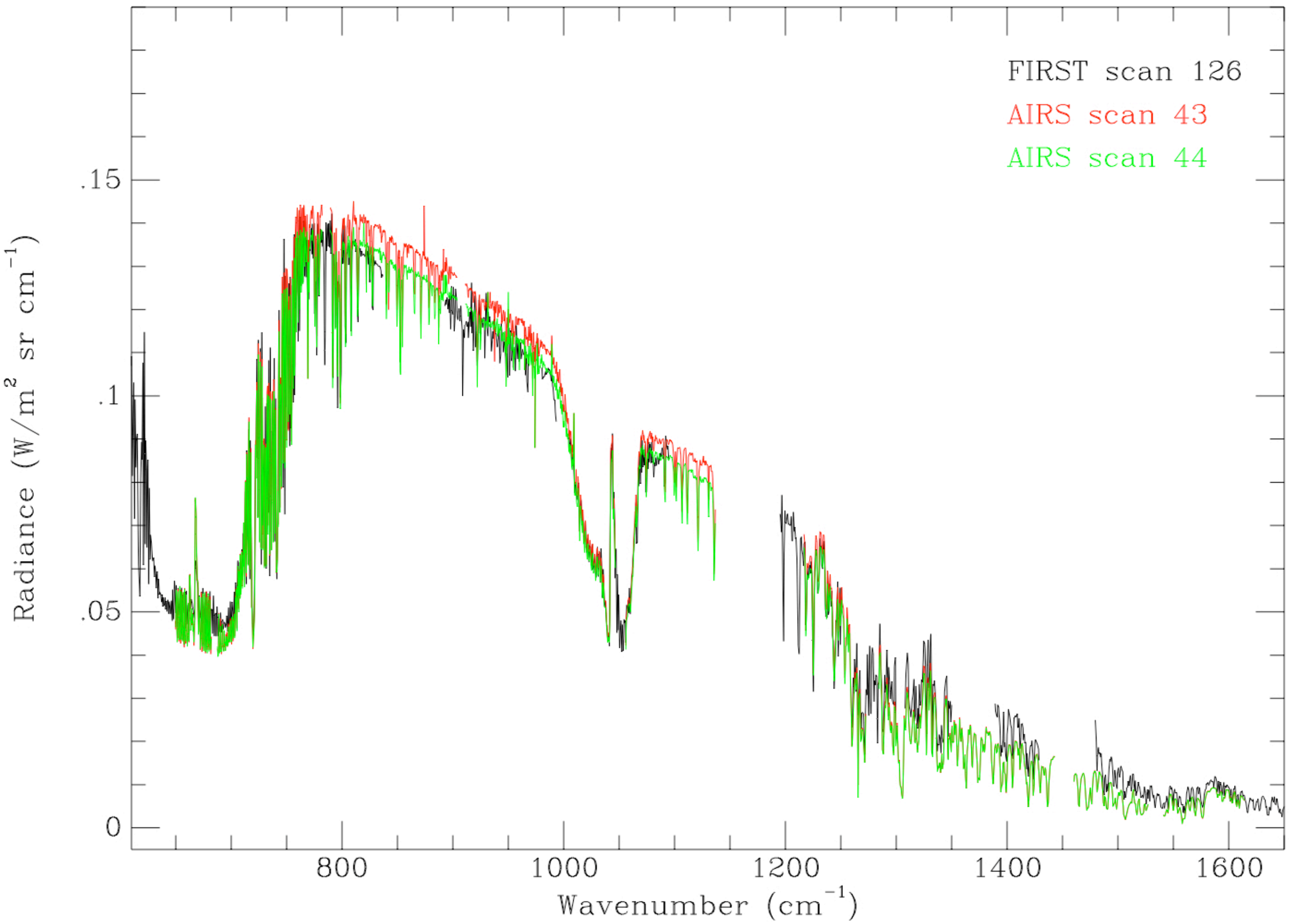

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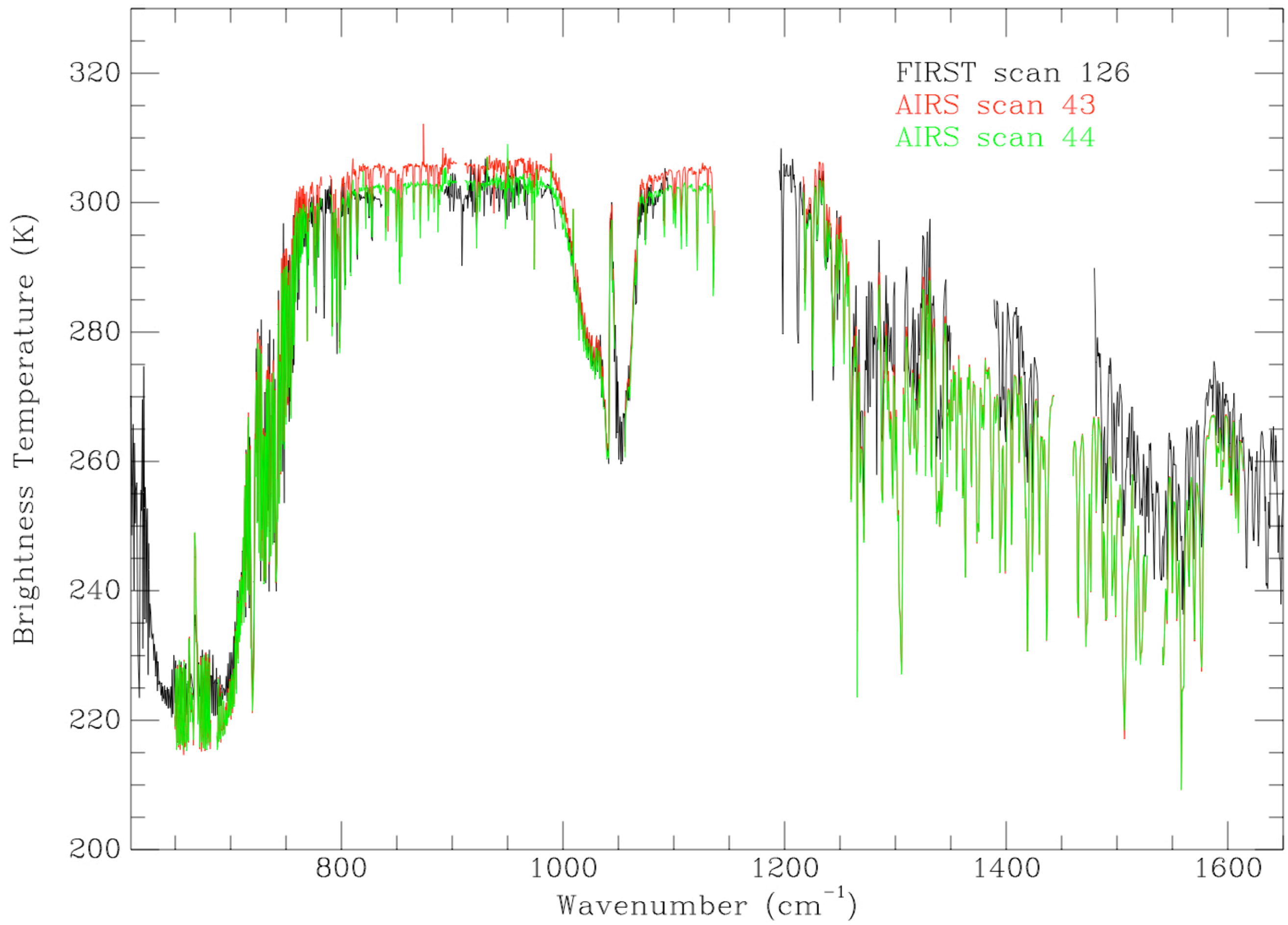

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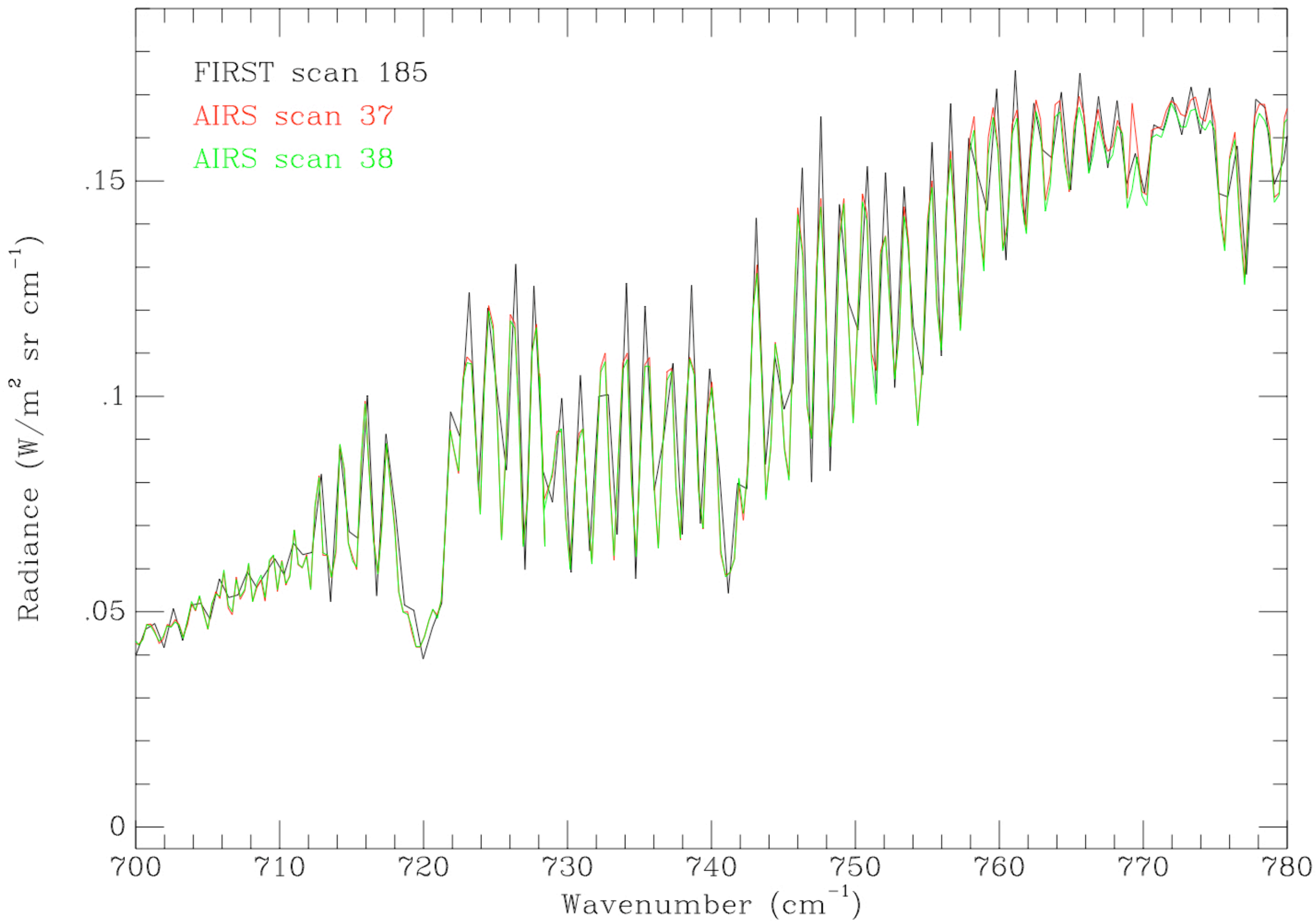

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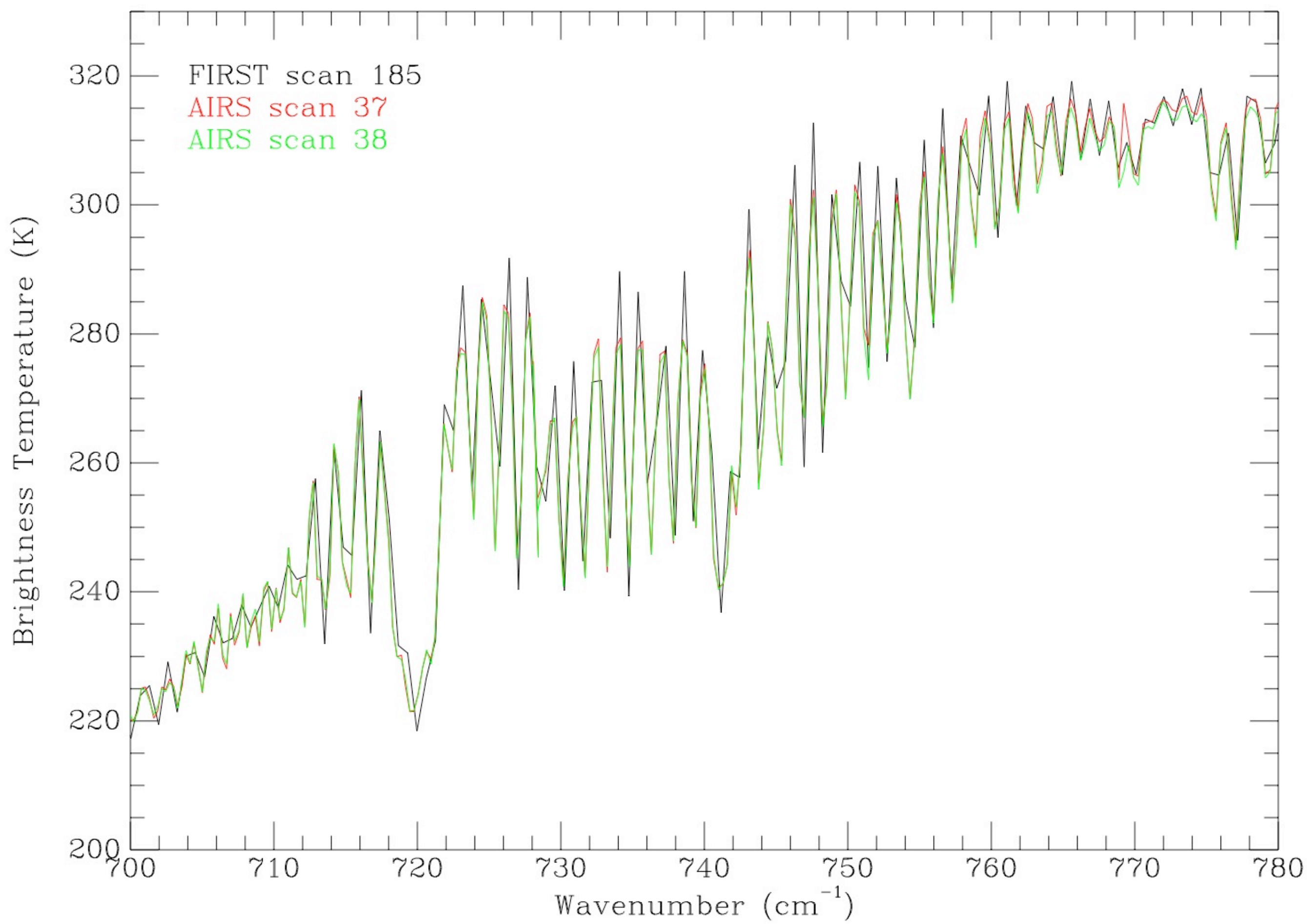

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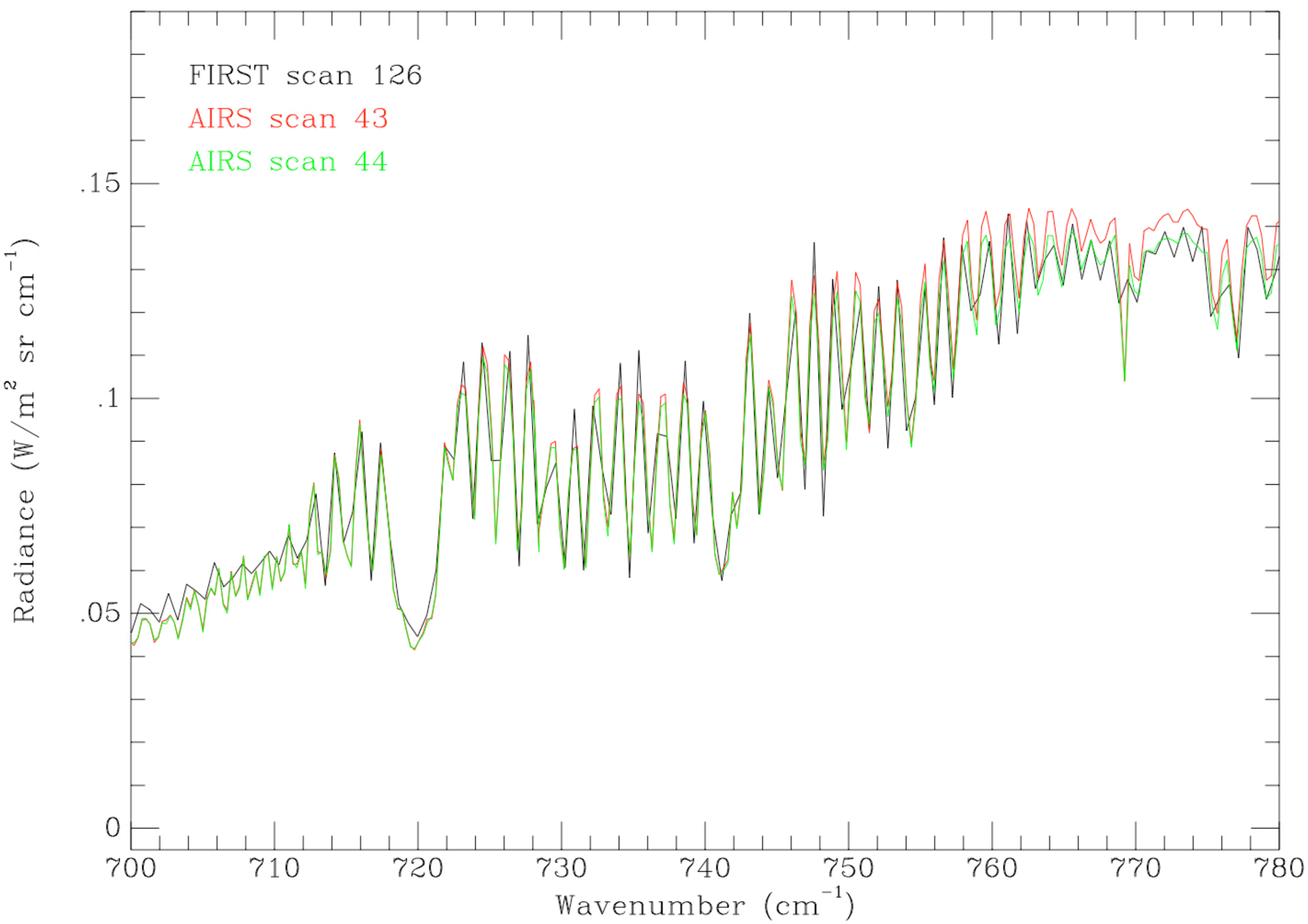

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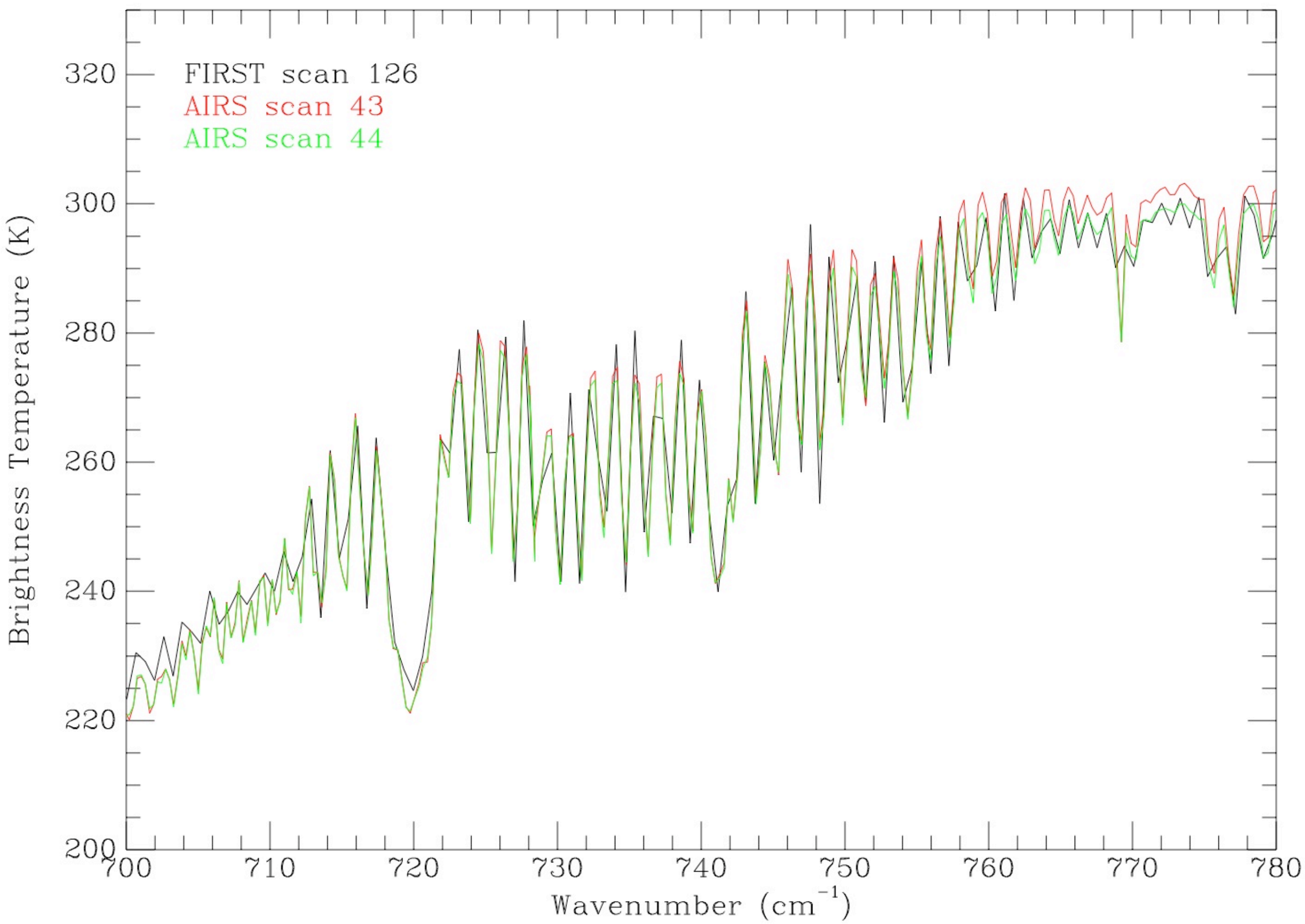
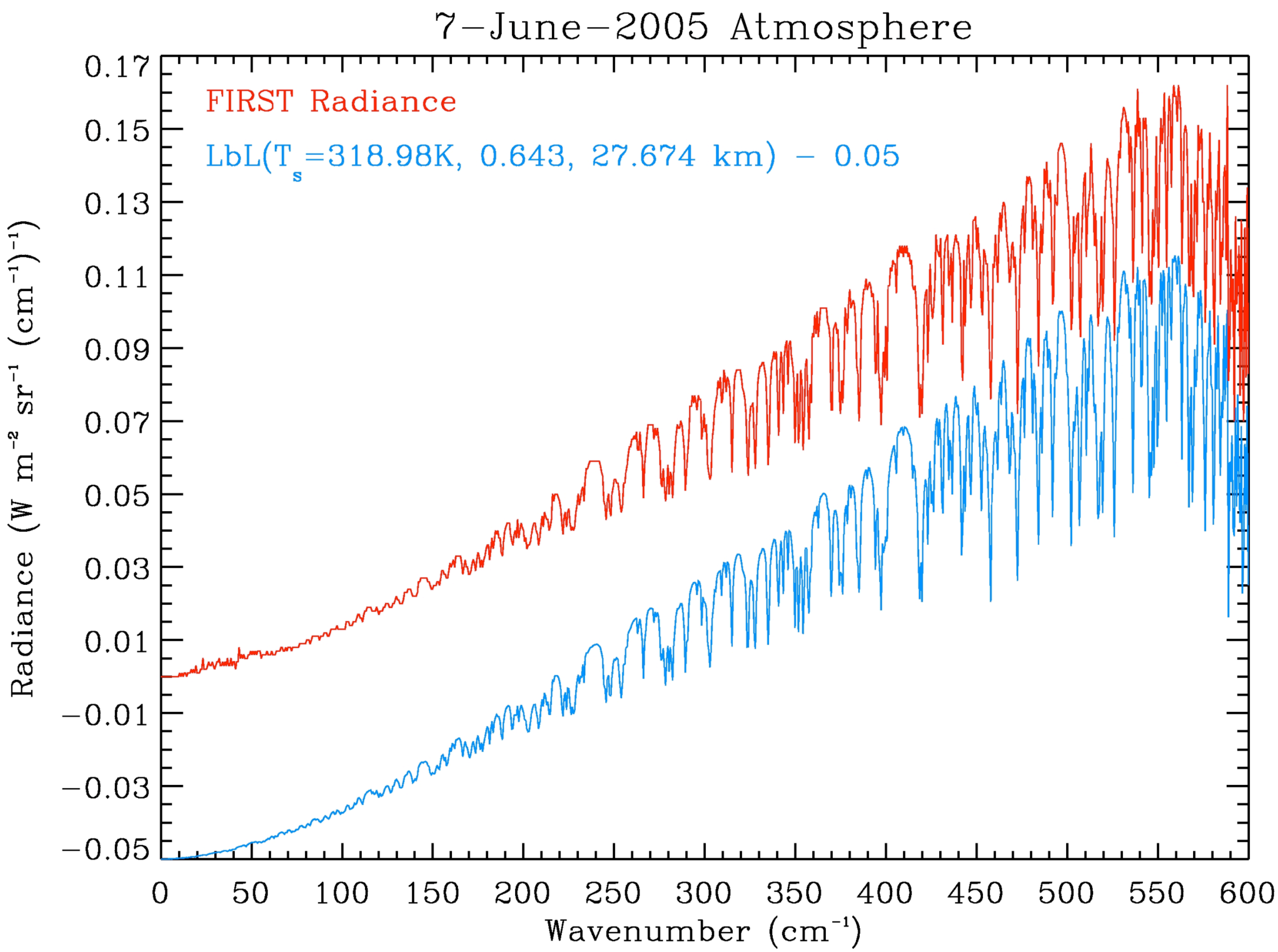
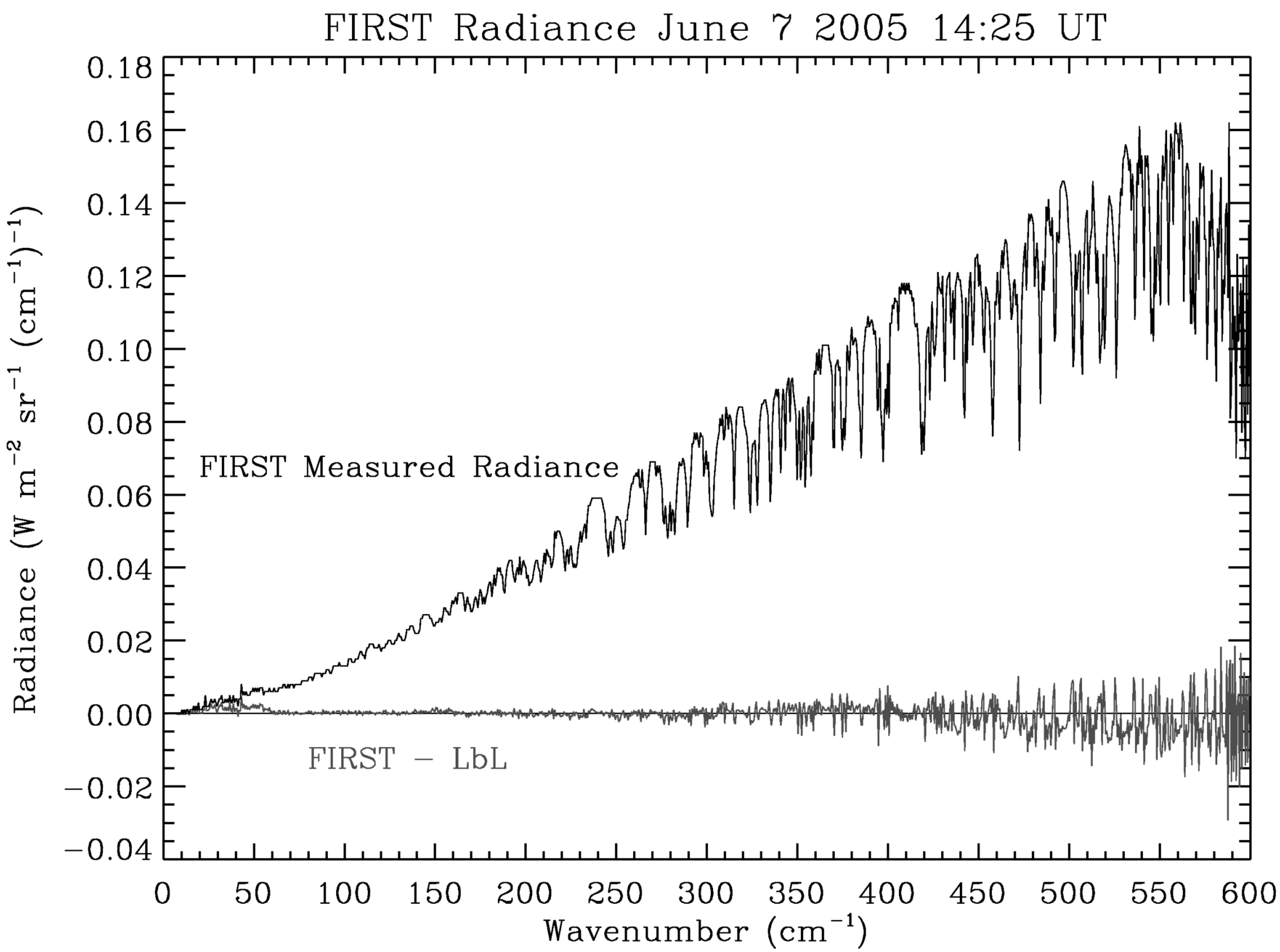


FIRST Spectra Compared with L-b-L Simulation
Demonstration of FIRST Recovery of Spectral Structure



Note: FIRST, LbL spectra offset by 0.05 radiance units

FIRST Measured, Calculated Radiance



Mlynczak et al., GRL, 2006

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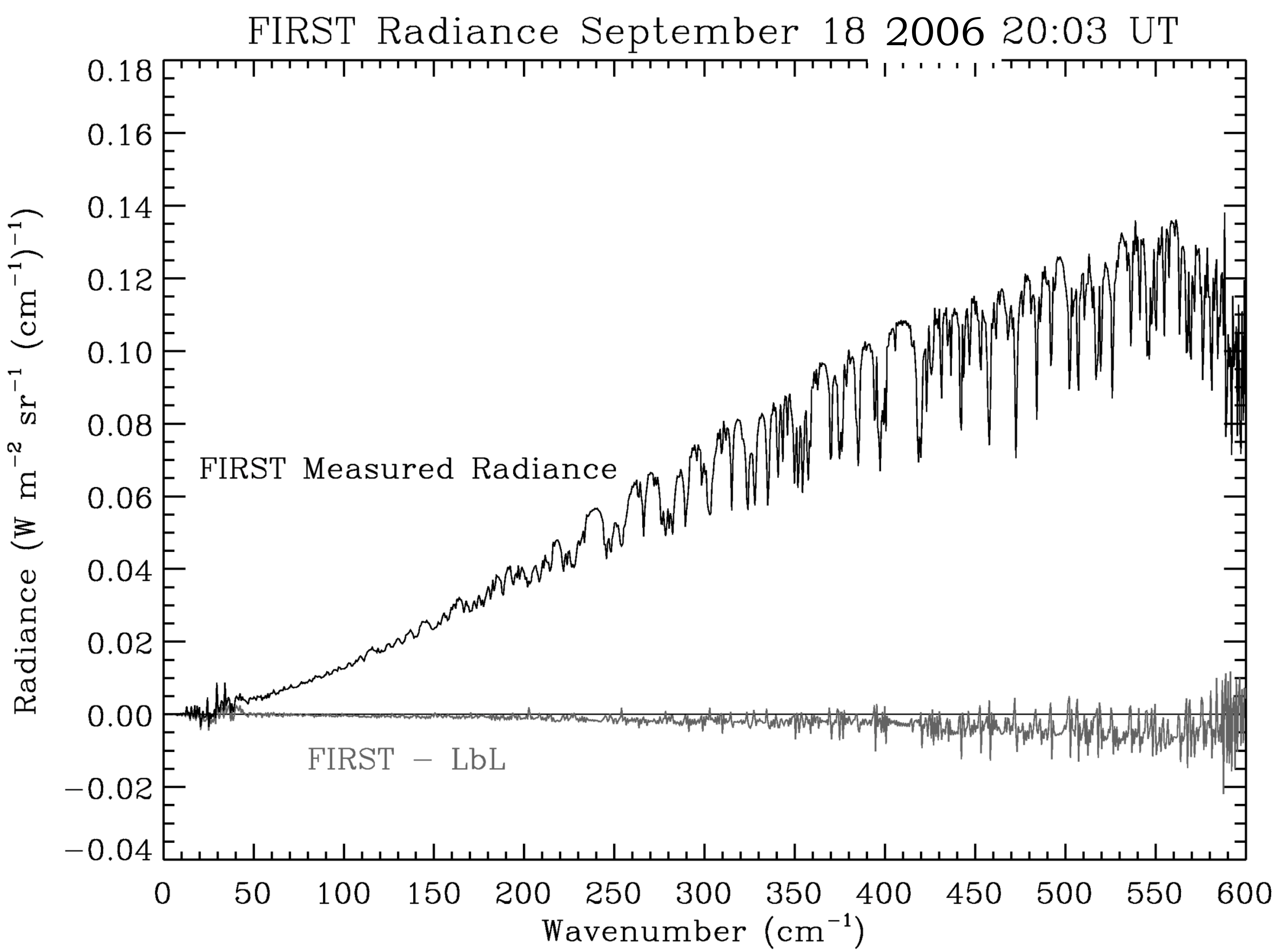
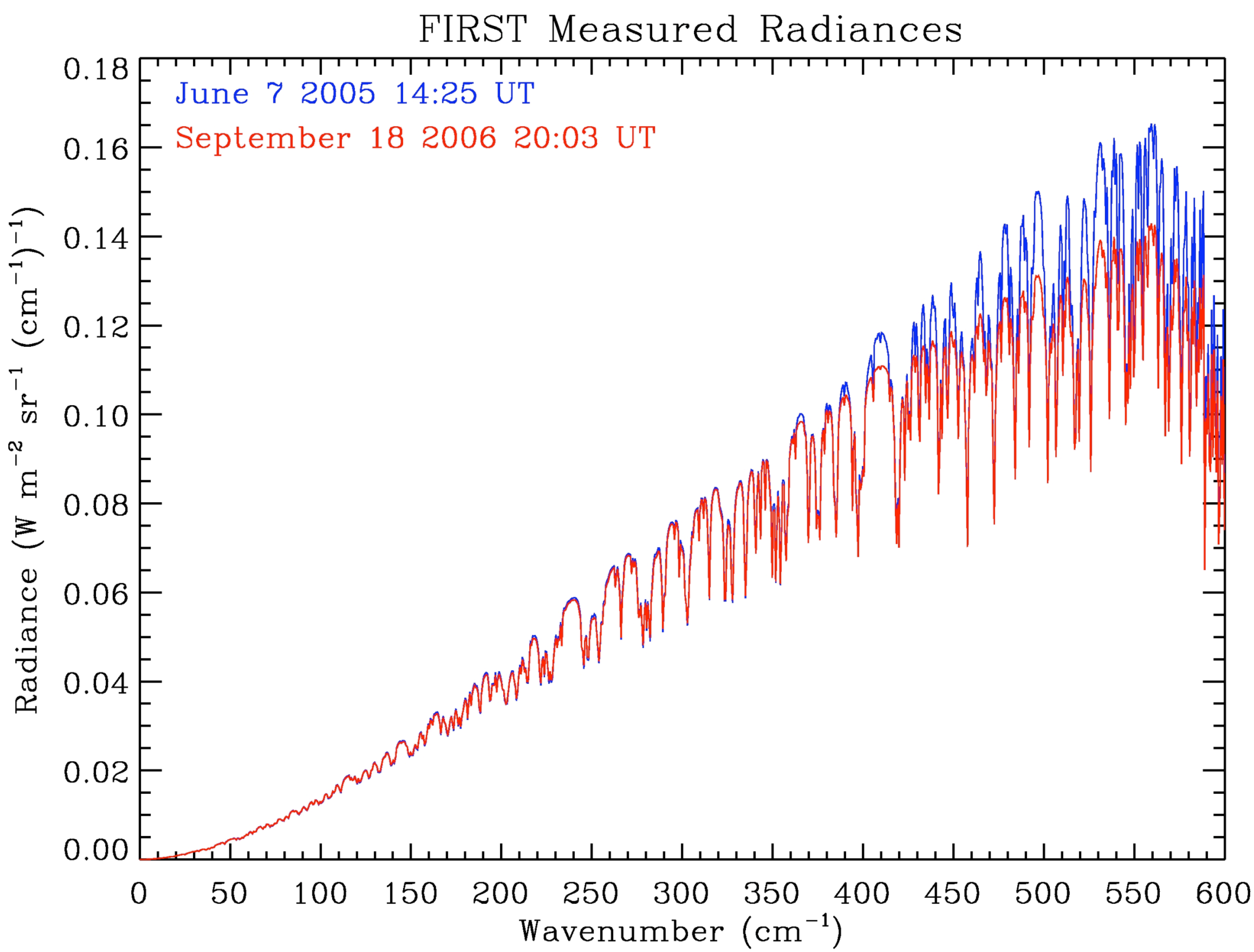
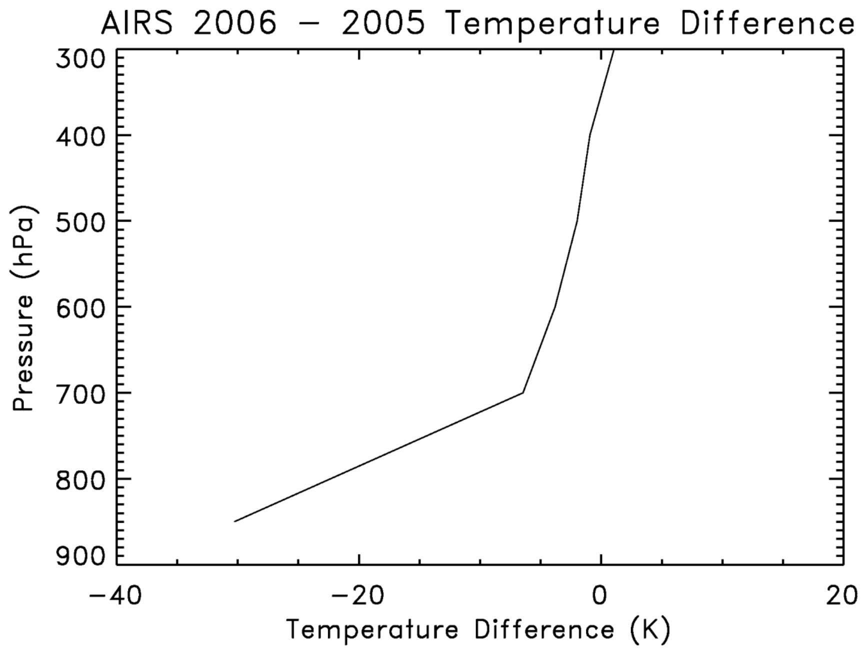
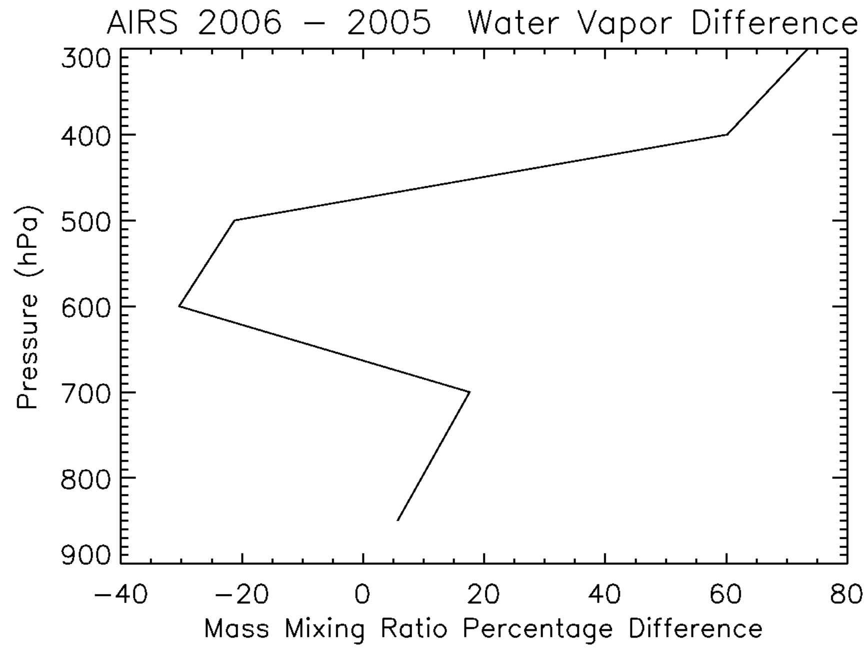


FIRST Radiances June 2005 and September 2006



Source of Far-IR Radiance Differences 2006 - 2005



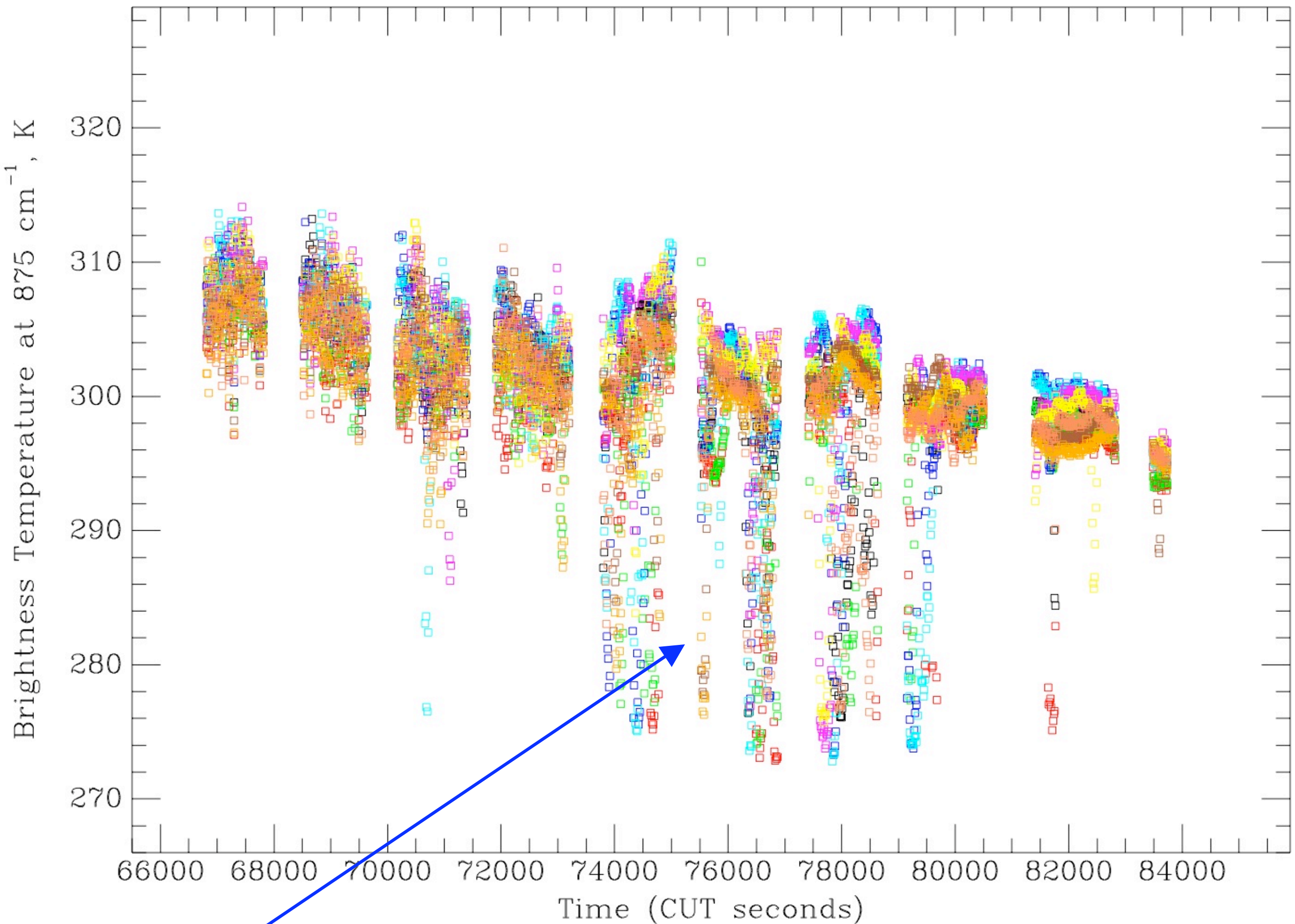


Lower troposphere a much cooler

Mid-Troposphere much drier

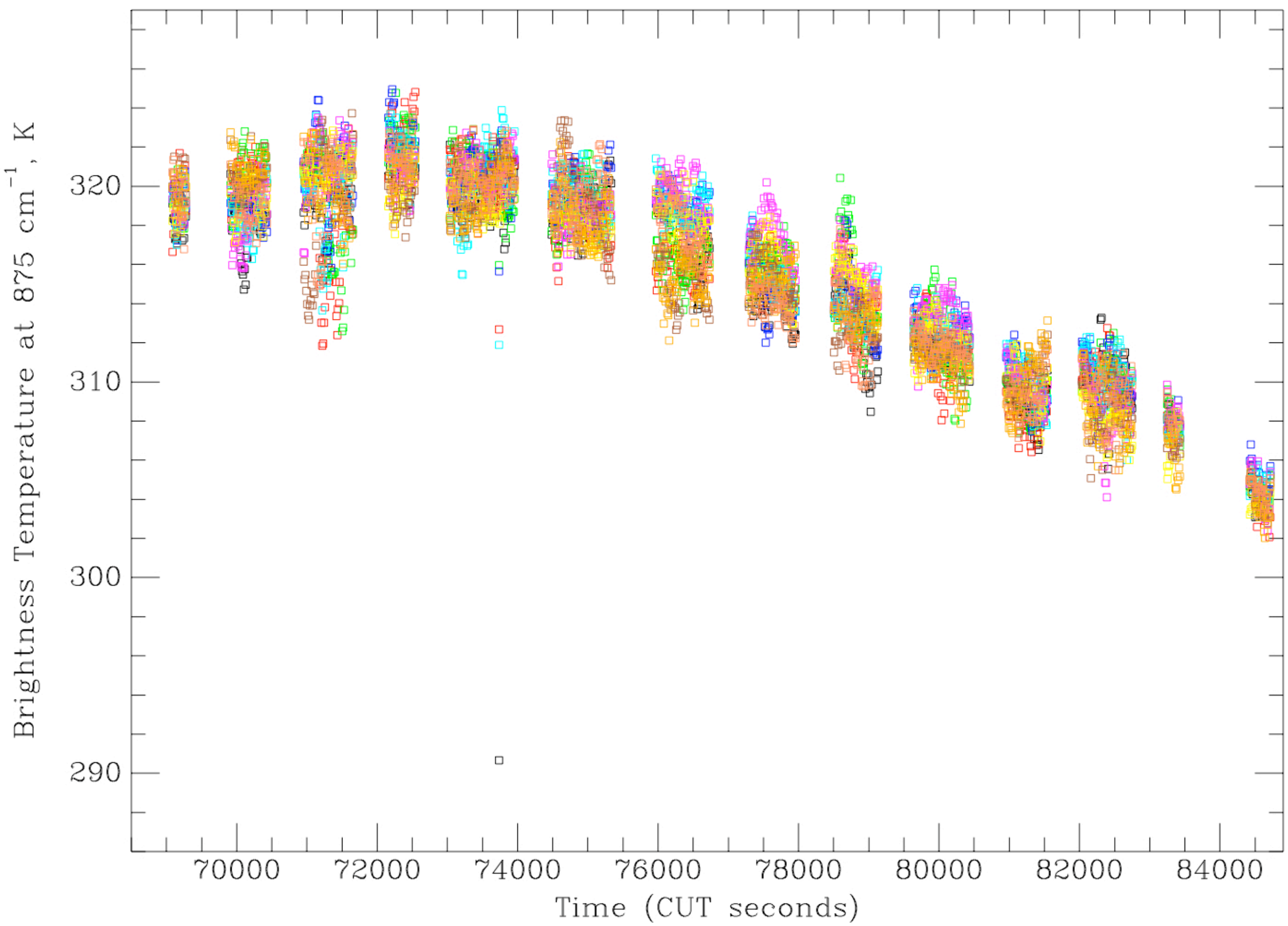
Lower radiances in 2006 due primarily to ~15 degree colder lower troposphere

FIRST 875 cm^{-1} T_B September 18 2006



T_B below 300 K indicate likelihood of low clouds observed by FIRST

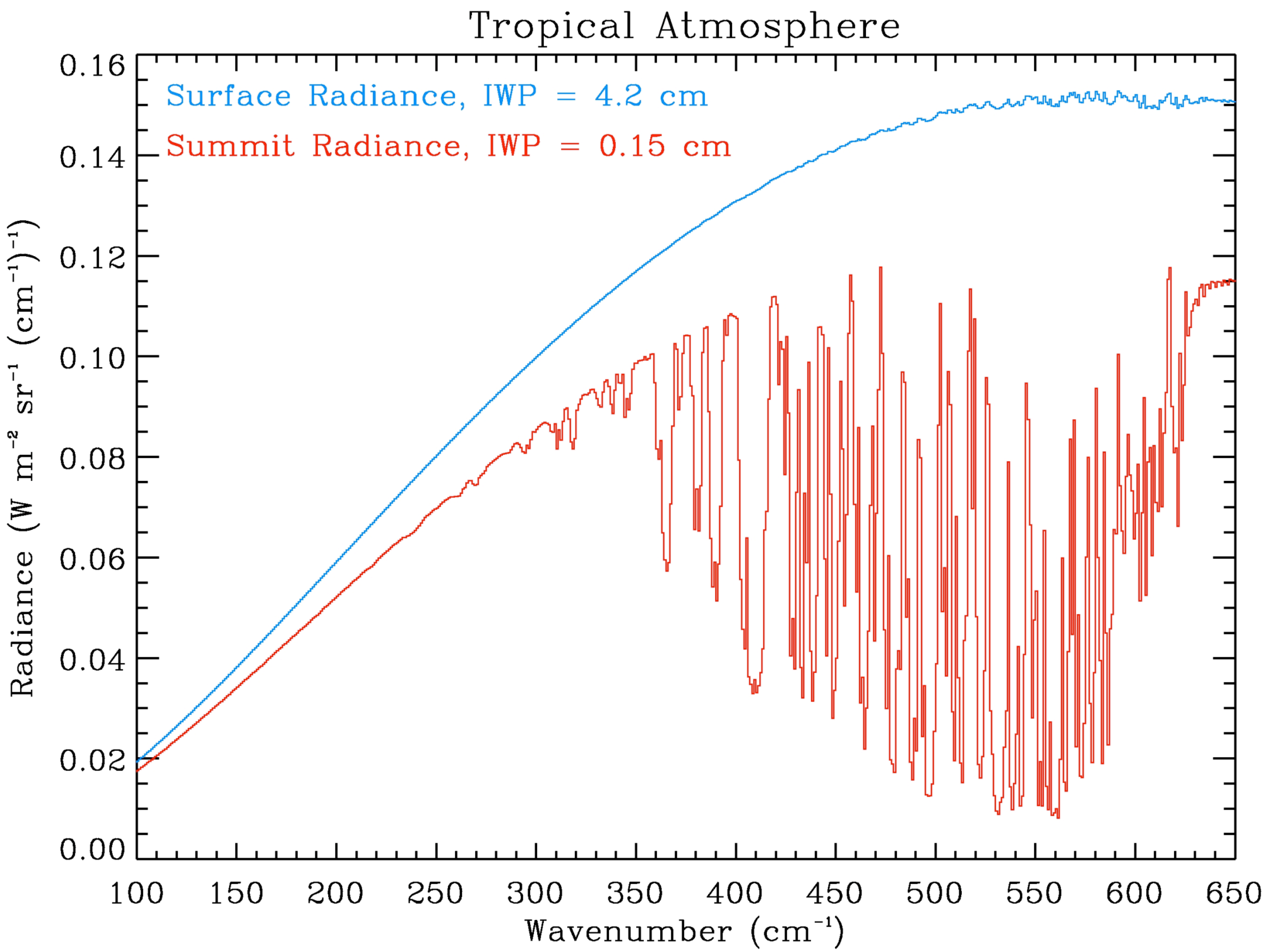
FIRST 875 cm^{-1} T_B June 7 2005



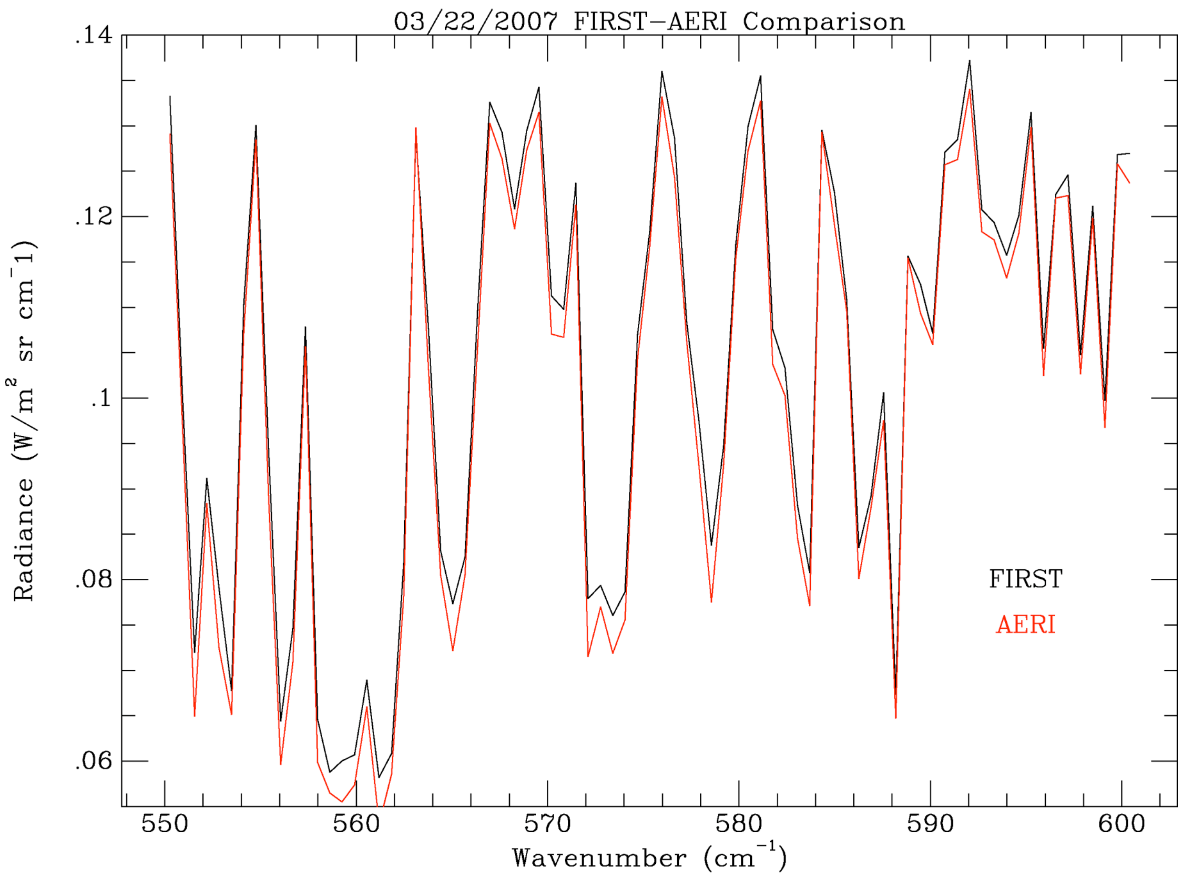
The Greenhouse Effect at the Ends of the Earth

- Far-IR Measurements – Ground based (zenith view)
- Cold and dry locations (less than 2mm PW)
  - Barrow, AK
  - Mauna Loa Observatory, HI
  - South Pole Station, Antarctica
  - Atacama Desert, Chile
- Far-IR open up to perhps 275 cm^{-1}
  - Derive radiative cooling of mid-troposphere
  - Observe far-IR optical properties of cirrus in windows
  - Validate far-IR water vapor spectroscopy

Far-IR Surface and Summit Zenith Radiances at MLO



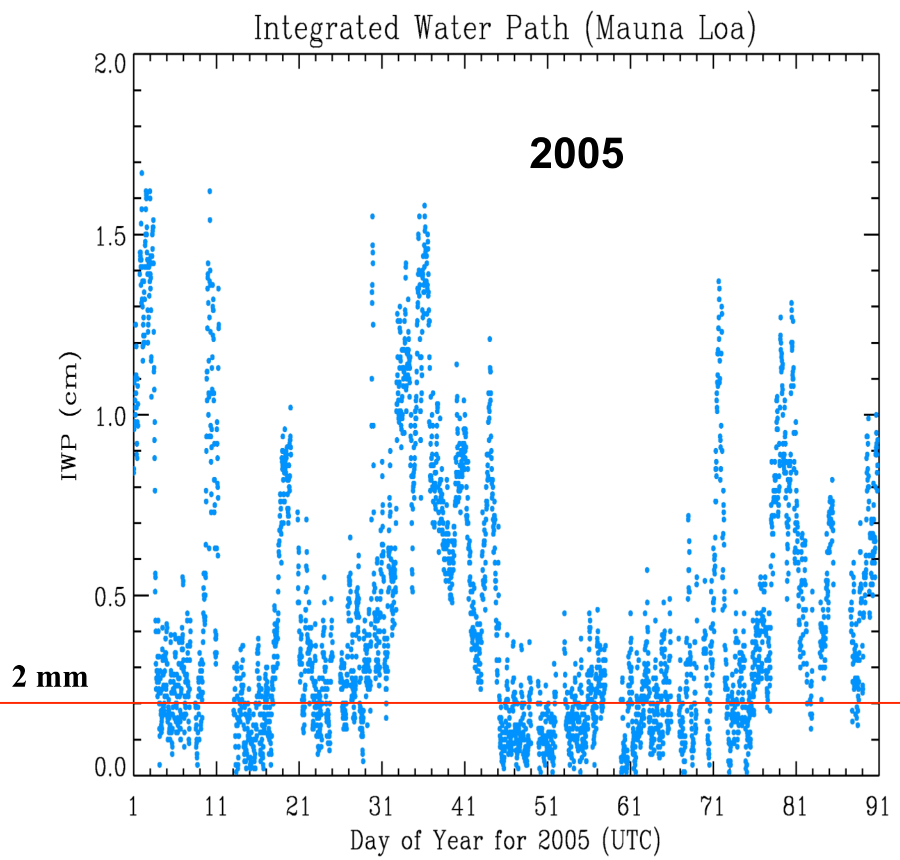
FIRST comparison with AERI
Ground-Based Zenith Views
March 22 2007 - Madison WI

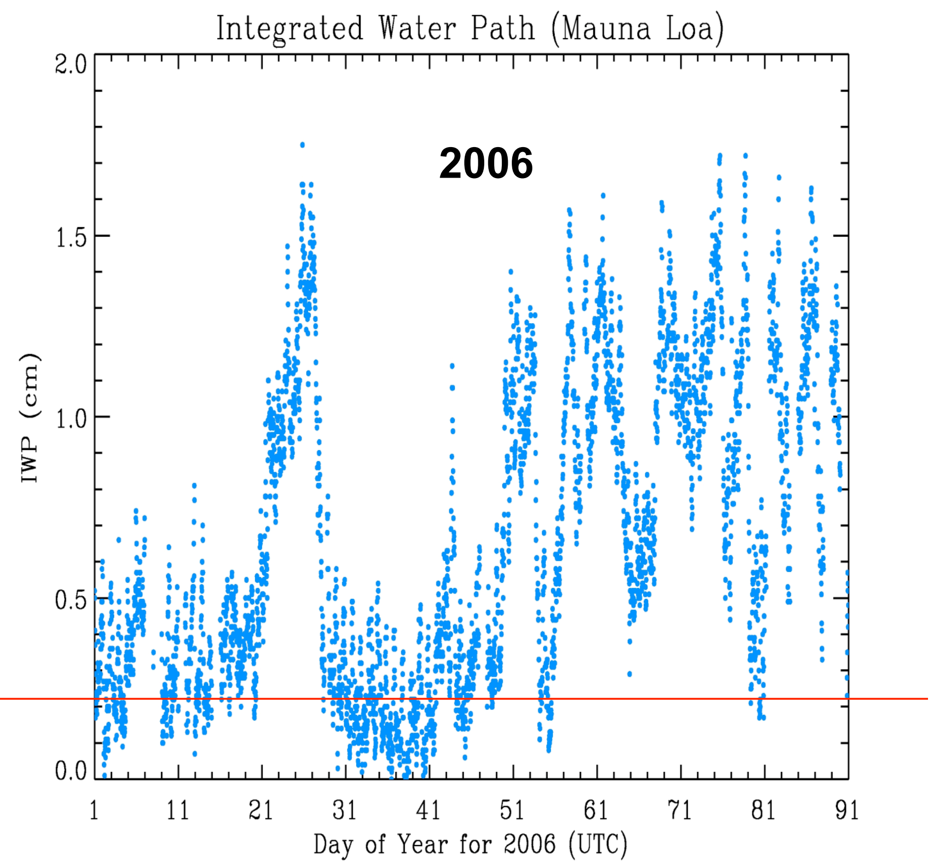


Initial comparisons vs. AERI demonstrate FIRST potential for ground-based campaigns

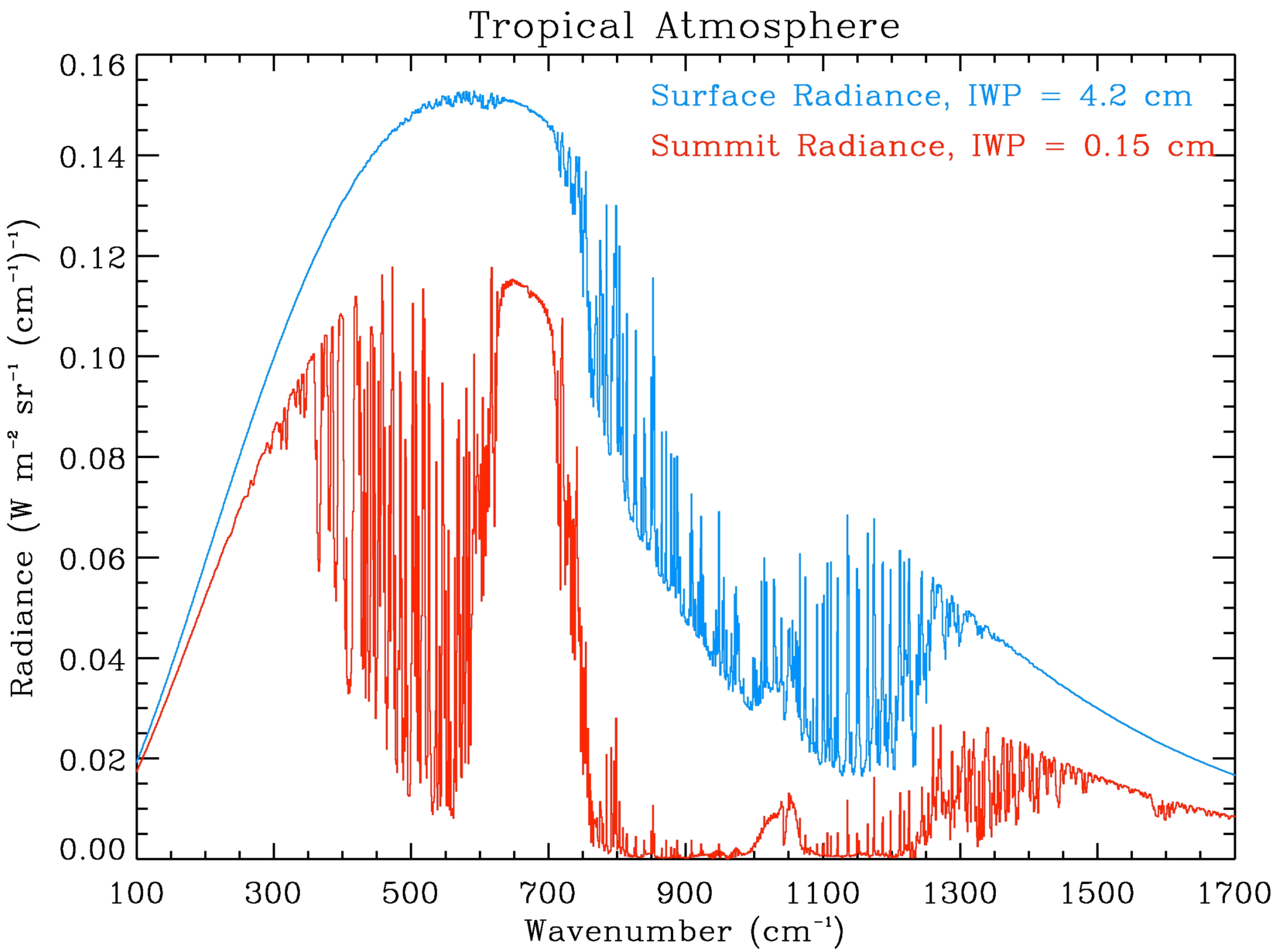
PWV at MLO 2005, 2006

PWV < 2 mm often in February, March

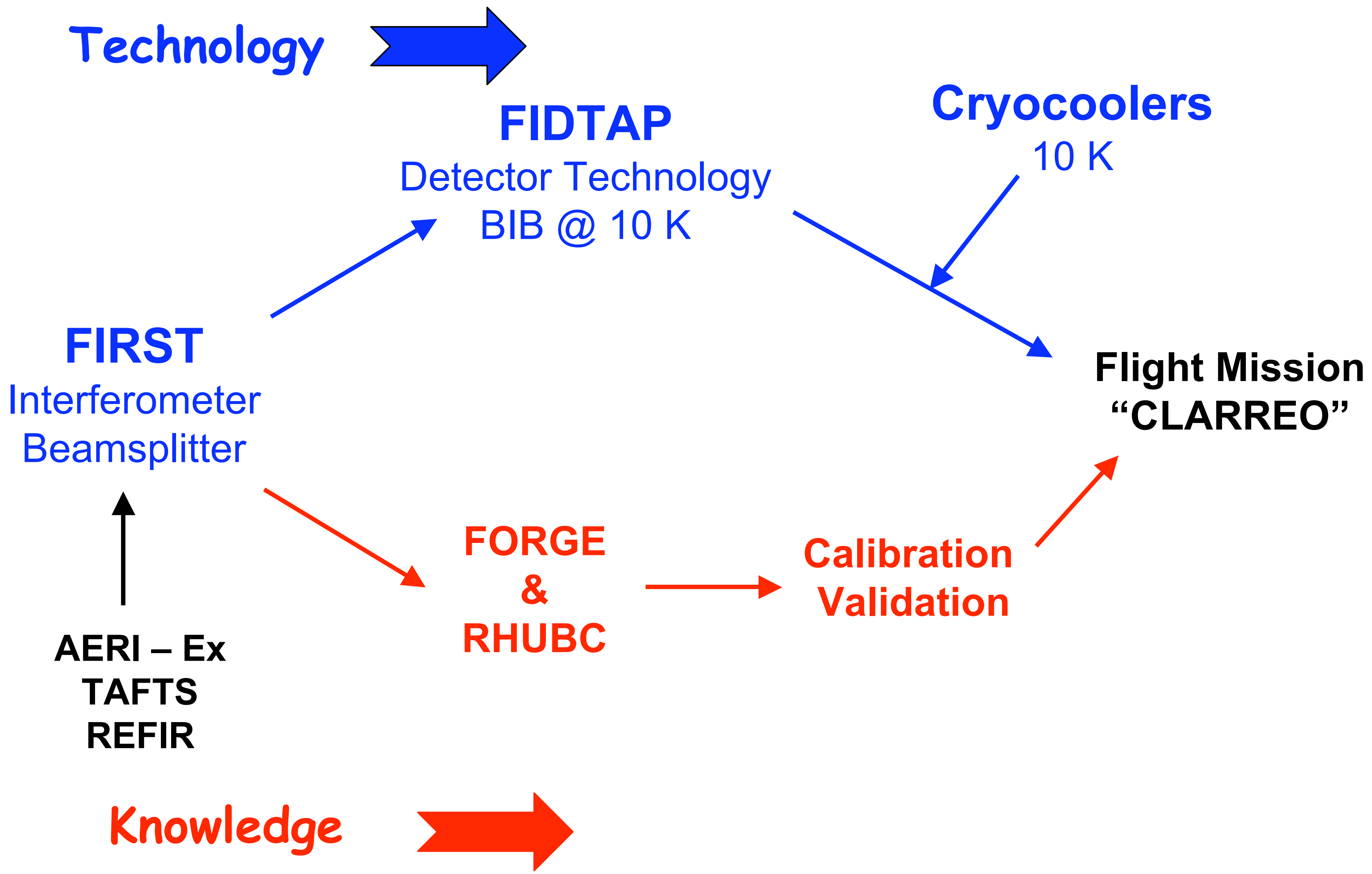




Surface and Summit Zenith Radiances at MLO



Far-Infrared – Future Directions



FIRST - Summary

- FIRST instrument successfully developed and demonstrated
  - Met or exceeded all technology development goals
  - Measures energetically significant spectrum 6 to 100 μm
- Calibration appears to be excellent - balloon and ground-based
- Substantial new science to be obtained from zenith views
  - Low H_2O venues such as Arctic, Antarctic, or high altitude
  - Cooling, H_2O spectroscopy, cirrus forcing
- On a path with related technology developments to achieve space based measurement
- MLO campaign pending approval -- 2/2008
- Proposing Antarctic balloon flight -- 1/2009
- Contributes directly to "CLARREO" mission outlined in recent NRC "Decadal Survey"

Data From Both Flights Available

~ 16,000 complete thermal infrared spectra

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FIRST - Acknowledgements

- NASA Earth-Sun System Technology Office (ESTO)
  - Instrument Incubator Program (IIP)
- NASA Langley Research Center
- NASA Science Mission Directorate
  - Radiation Sciences Program, Hal Maring
- Utah State University Space Dynamics Laboratory (SDL)
- Harvard Smithsonian Center for Astrophysics
- NASA Columbia Scientific Balloon Facility
- DRS Technologies, Cypress, CA - Detector Technology Partnership

FIRST International Science Team

- Marty Mlynczak (PI) NASA Langley
- Dave Johnson (TL) NASA Langley
- Charlie Hyde (PM) NASA Langley (retired)
- Stan Wellard (PM) Utah State/SDL
- Gail Bingham Utah State/SDL
- Ken Jucks Smithsonian Astrophysical Observatory
- Wes Traub Smithsonian Astrophysical Observatory

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- Dave Kratz NASA Langley
- Ping Yang Texas A & M University
- Bill Smith NASA Langley/U. Wisconsin
- Lou Smith National Institute of Aerospace
- Paul Stackhouse NASA Langley
- Chris Mertens NASA Langley
- Bob Ellingson Florida State University
- Rolando Garcia NCAR ACD
- Bill Collins NCAR CGD
- Brian Soden GFDL
- John Harries Imperial College, London
- Rolando Rizzi U. Bologna, Italy

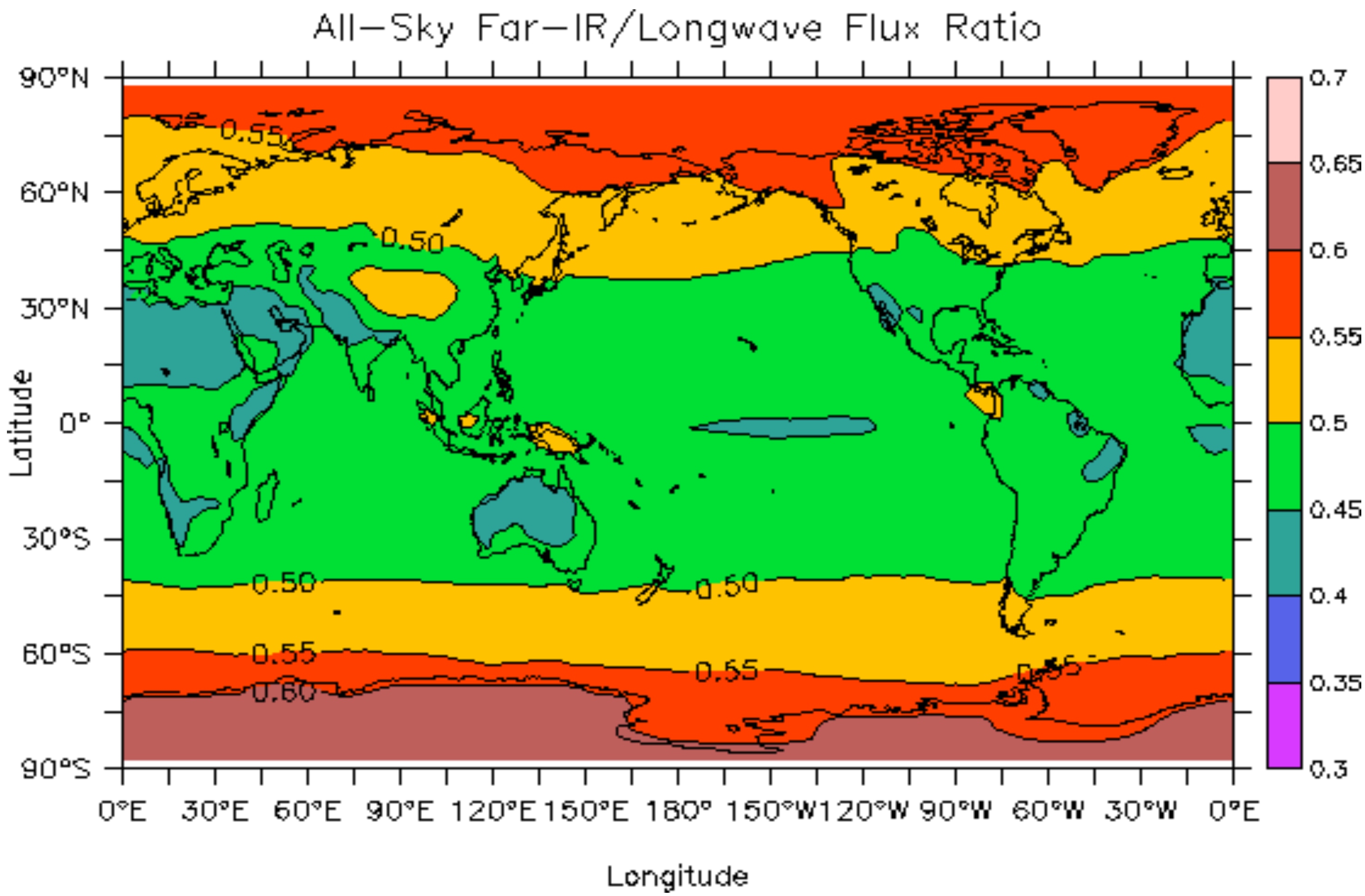
Other Far-IR Programs

- Tropospheric Airborne FTS (TAFTS)
  - Imperial College, London, UK
  - 800 cm^{-1} to 80 cm^{-1}
  - 0.1 cm^{-1} resolution

- Radiation Explorer in the Far-Infrared (REFIR)
  - University of Bologna & other institutions, Italy
  - 1100 cm^{-1} to 100 cm^{-1}
  - 0.5 cm-1 resolution

- These projects predate FIRST by a few years, but pursue essentially the same science

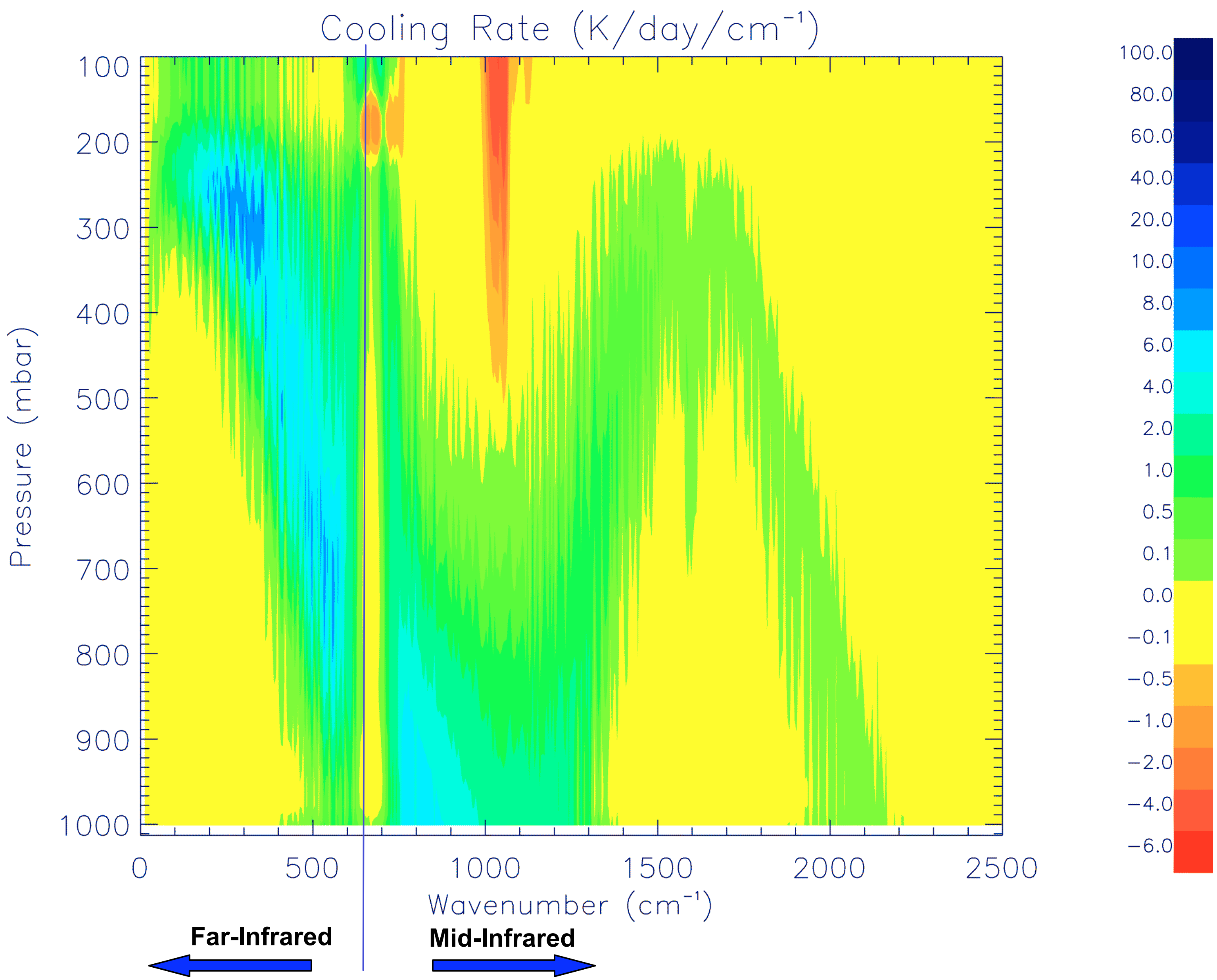
FIRST



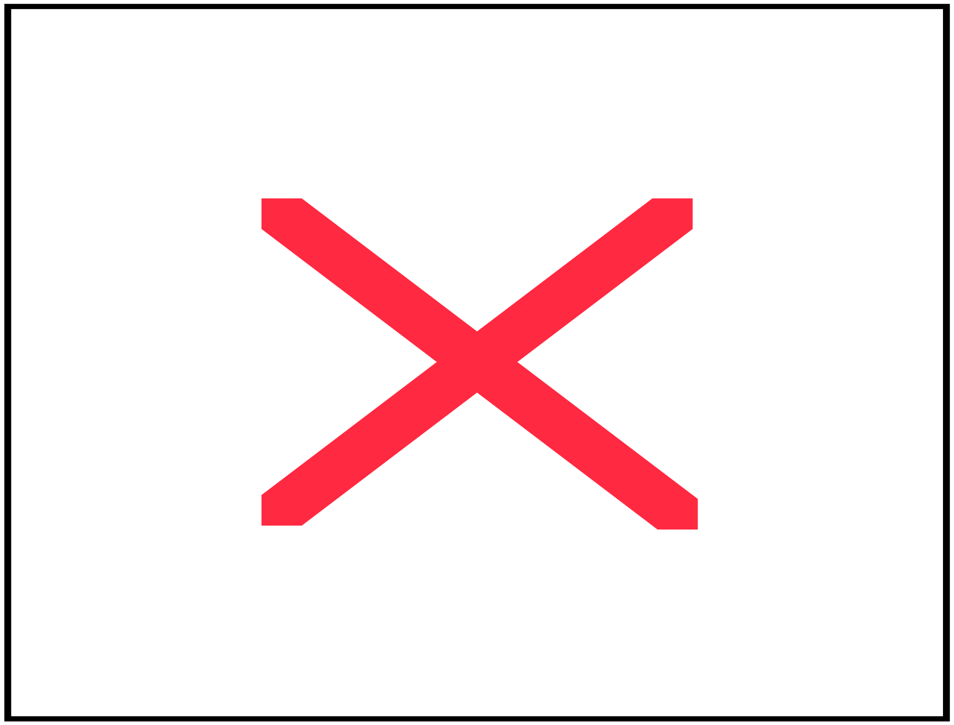
Annual mean TOA fluxes for all sky conditions from the NCAR CAM

Reference: Collins and Mlynczak, Fall AGU, 2001

Infrared Cooling Rate



FIRST – Sensitivity to Cirrus Clouds

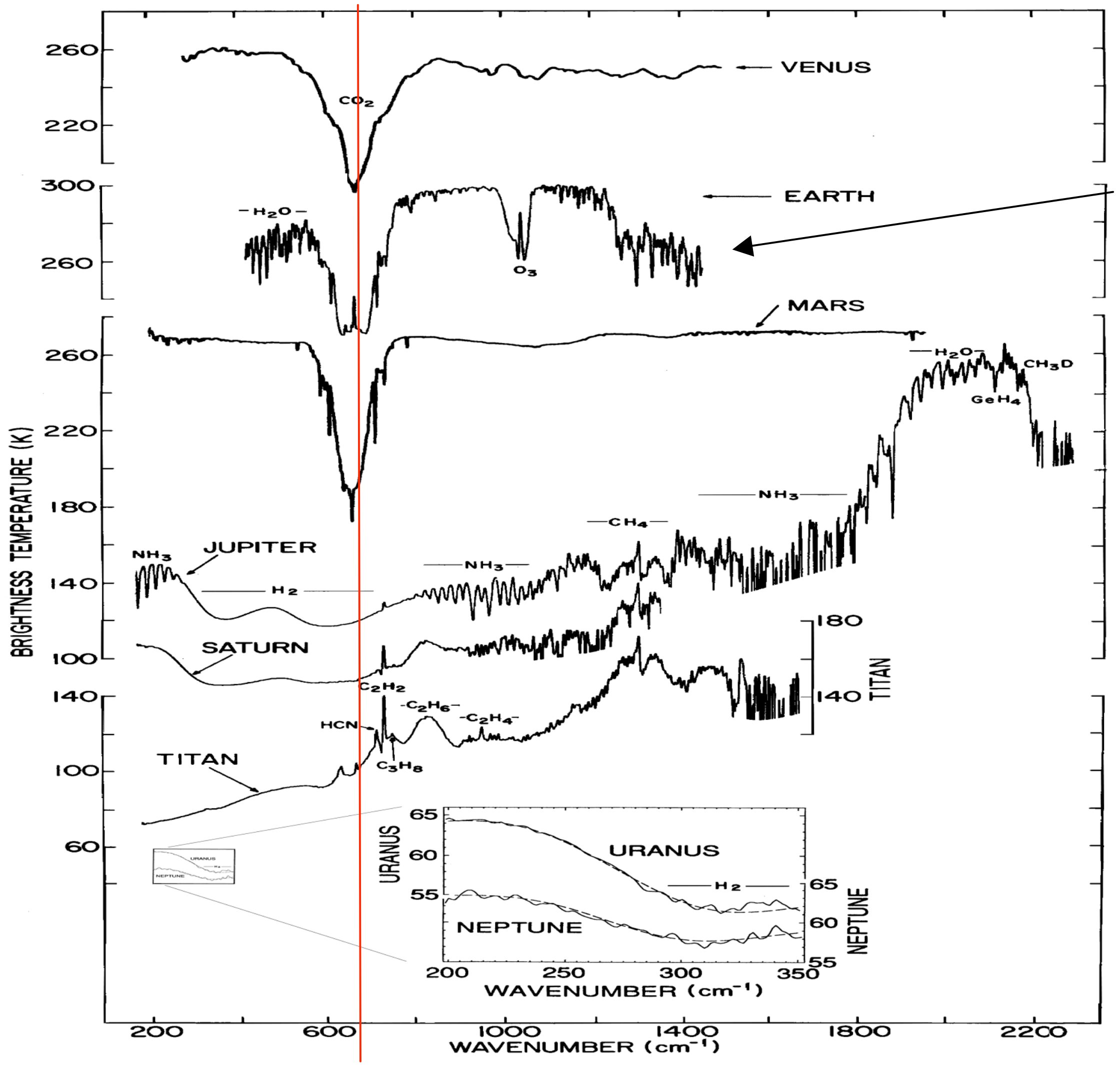


Brightness temperature difference between two channels ν_1=250.0 cm^{-1} and ν_2=559.5 cm^{-1} as a function of effective particle size for four cirrus optical thicknesses

FIRST spectra can be used to derive optical thickness of thin cirrus clouds (τ < 2)

Reference: ***Yang et al.*****, JGR, 2003**

Far-IR Measurements in our Solar System

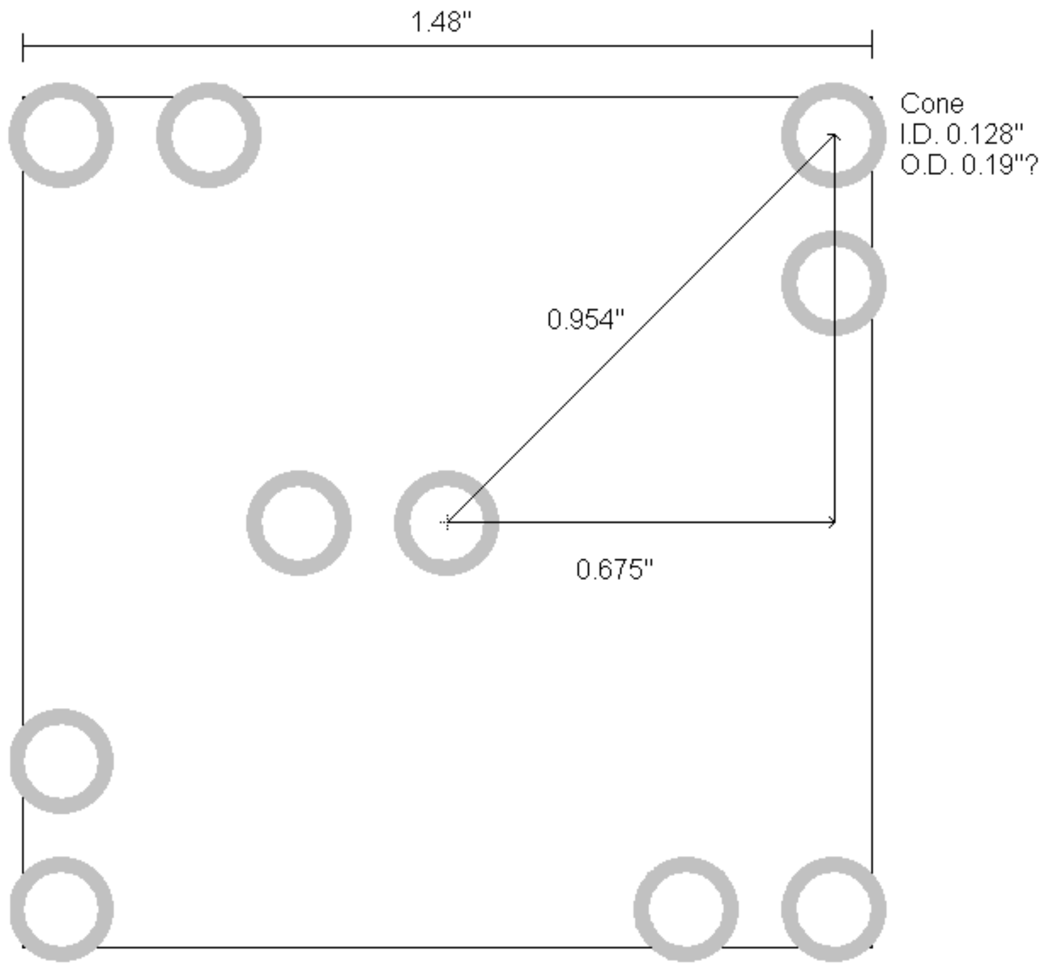


Nimbus III/IV, 1969/70

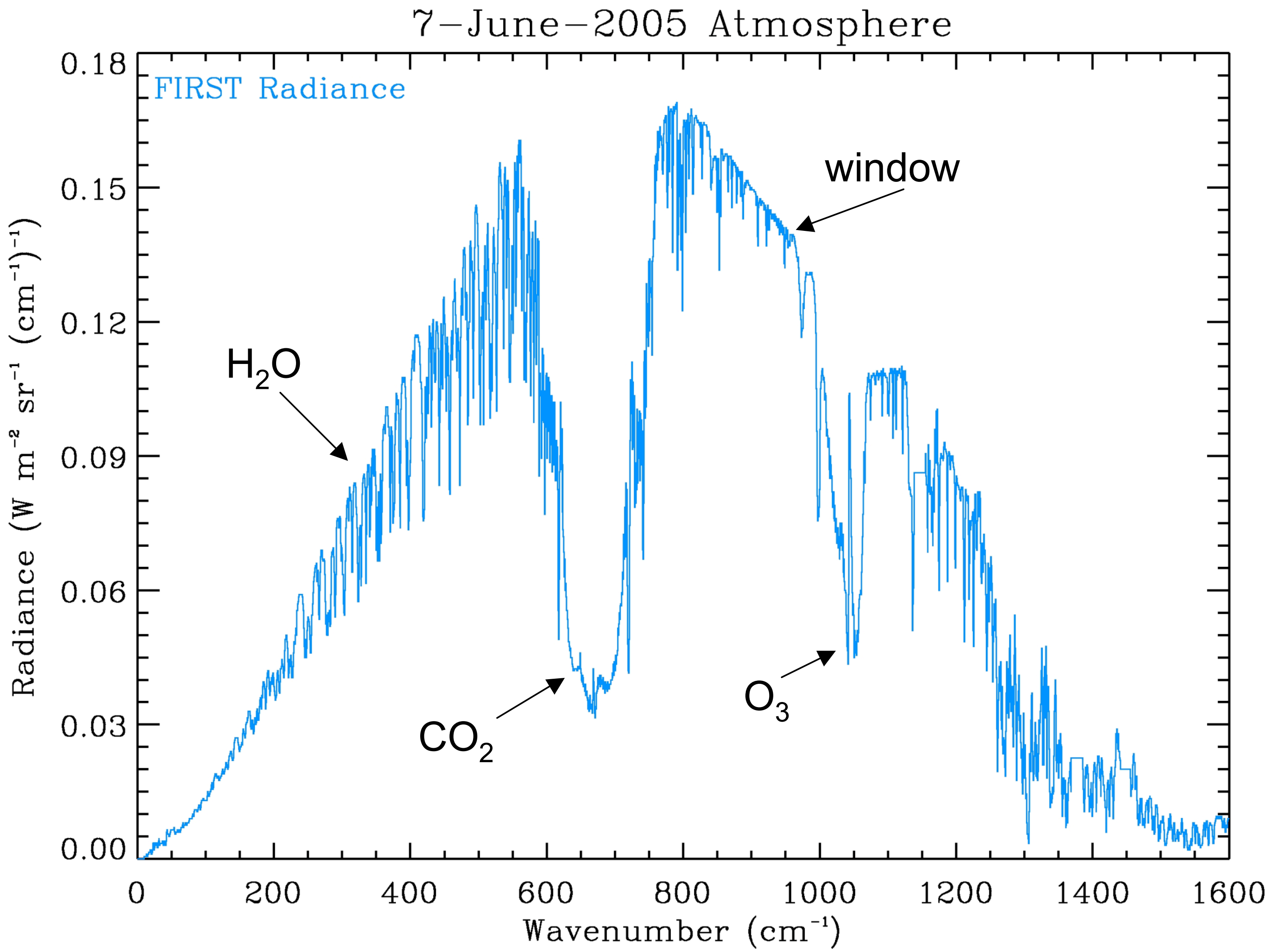
Far – IR least measured on Earth → FIRST project

Reference Hanel et al., 2003

FIRST Winston Cone Array



FIRST "First Light" Spectrum



Reference: Mlynczak et al., 2006